ELEMENT 5 - WATER QUALITY MONITORING – 2011

The Department of Water Resources (DWR) has been monitoring water quality as part of the South Delta Temporary Barriers project since 1991 to investigate water quality conditions in the South Delta that may be affected by temporary barrier installations and operations. In 2011, DWR continued its South Delta water quality sampling program, which consisted of continuous sampling only. DWR stopped the bi-monthly discrete water quality sampling of biological constituents and nutrients after 2010. The information collected by this program is required for compliance with a 401 Water Quality Certification issued by the Central Valley Regional Water Quality Control Board. For detailed information on the South Delta Improvements Program and the Temporary Barriers Project please visit DWR's Bay-Delta Office website at http://baydeltaoffice.water.ca.gov/sdb/.

Historically, DWR conducted discrete sampling on a weekly basis at 10 locations to monitor physical and biological constituents, as well as nutrients. The objective of this discrete program was to monitor the effects of barrier operations on water quality. To ensure that adequate data was collected before, after, and during the operational period of the barrier, DWR started discrete sampling two weeks before the barriers were installed and did not conclude until two weeks after all the barriers were removed. Staff conducted sampling every Tuesday morning to target the time when dissolved oxygen concentrations tend to be lowest.

In 1998, Central District[1] (CD) initiated a pilot program to test the viability of establishing permanent multi-parameter water quality stations in the South Delta to continuously monitor water temperature, pH, dissolved oxygen, specific conductance, and turbidity. CD established this program to better understand barrier installations in accordance with the following: 1) to determine the feasibility of collecting reliable time-series water quality data; 2) to develop an understanding of dynamic water quality conditions in a tidally influenced system; and 3) to establish and maintain long-term continuous data records in the South Delta for analysis.

This continuous water quality monitoring program began with two stations: Old River at Tracy Wildlife Association and Middle River at Howard Road. Central District staff determined that the time-series data generated from these two sites was reliable, accurate, and precise when compared to calibration standards and field data. The success of the pilot program resulted in the decision to expand the continuous monitoring program. DWR designed this expansion to complement the existing discrete stations. As a result, CD staff installed continuous monitoring stations at each of the 10 discrete monitoring locations between 2000 and 2006. After the installation of multi-parameter instruments at the discrete locations was complete, the weekly dissolved oxygen sampling was terminated and monitoring was changed from weekly to bi-monthly. This bi-monthly discrete sampling of biological constituents and nutrients was terminated after 2010.

In 2005, DWR drafted a monitoring proposal for the South Delta Permanent Barriers Project that included the implementation of three new continuous multi-parameter water quality stations. The proposed station locations were Grant Line Canal near Old River, Victoria Canal, and Doughty Cut above Grant Line Canal. The water quality instruments at Grant Line Canal near Old River and Victoria Canal were co-located with an acoustic doppler current profiler instrument, which provides time-series water quality data that could be correlated with time-series flow data. The purpose of the Doughty Cut station was to document possible improvements to water quality based on permanent barrier operation. In addition, all three of these stations provide water quality information for the calibration and validation of the DSM2 model for the South Delta. CD staff installed multi-parameter water quality stations at Doughty Cut above Grant Line Canal in 2006 and at Victoria Canal and Grant Line Canal near Old

[1] As of 2010, the Central District is now named North Central Region Office (NCRO) due to reorganization.

River in 2007. The data collected at these three sites are included in this chapter for data evaluation and analysis purposes.

In addition to satisfying the monitoring and reporting requirements mandated by the 401 Water Quality Certification for the Temporary Barriers Project, DWR staff will address the following questions in this chapter:

1) How do the water quality data collected at all of the sites compare to established water quality standards specifically for pH and dissolved oxygen?
2) Are the dissolved oxygen concentrations significantly different at the sites closest to the temporary barriers compared to the sites further upstream and/or downstream in the same waterbody?
3) For the above two questions, do the analyses differ among seasons?

MATERIALS AND METHODS

Station Locations

DWR collects continuous water quality data at thirteen monitoring stations in the South Delta: four in Middle River, four in Old River, four in Grant Line Canal and one in Victoria Canal. Figure 6-1 illustrates these site locations, and Table 6-1 provides the station coordinates and the date the station was established. DWR provides real-time data for nine of the thirteen South Delta stations on the DWR California Data Exchange Center (CDEC):

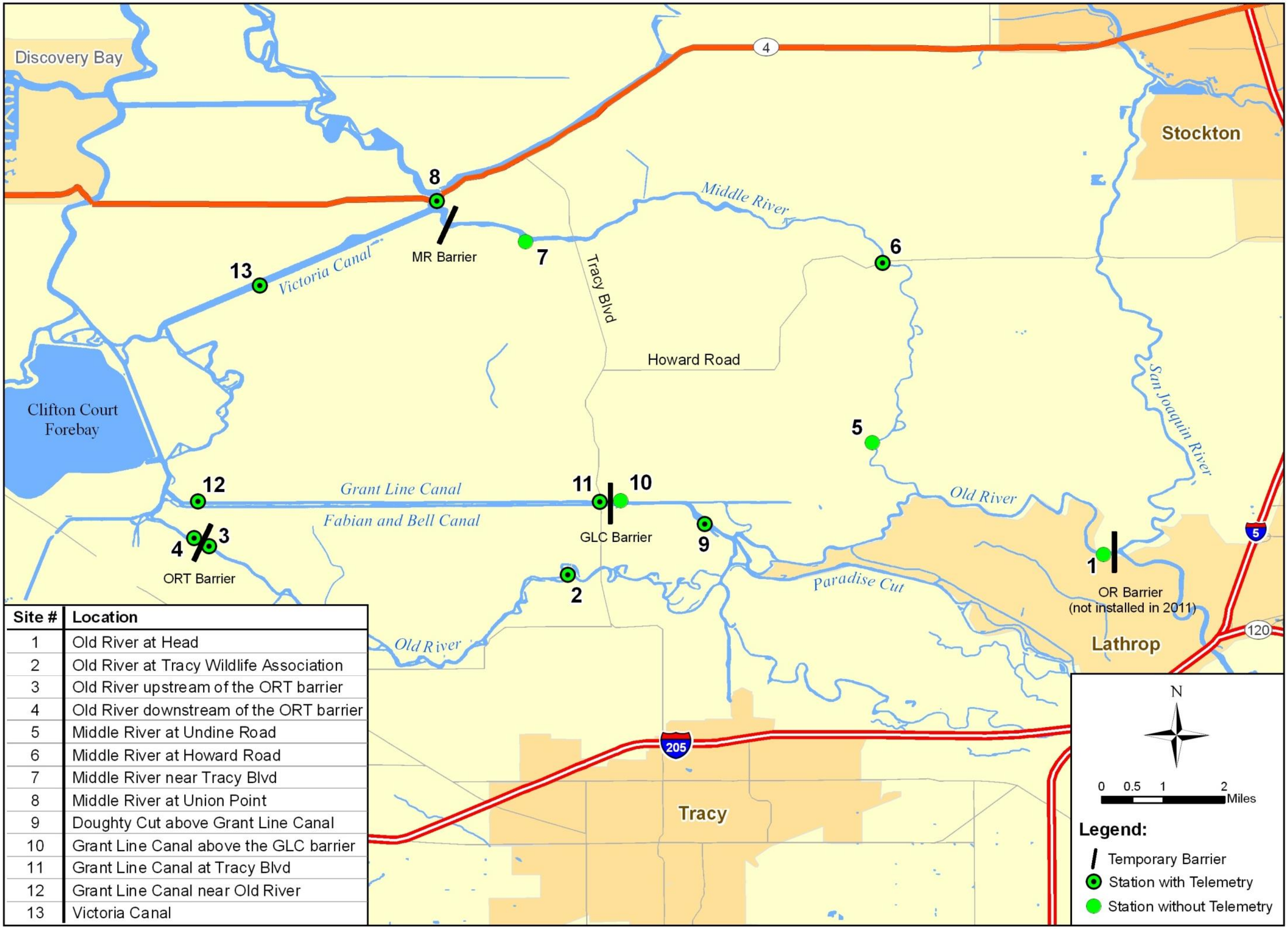
- Doughty Cut above Grant Line Canal
- Grant Line Canal at Tracy Blvd
- Grant Line Canal near Old River
- Middle River at Howard Road
- Middle River at Union Point
- Old River at Tracy Wildlife Association
- Old River downstream of the ORT barrier
- Old River upstream of the ORT barrier
- Victoria Canal

To access data for these stations select "real-time data" from the main menu on the CDEC website (http://cdec4gov.water.ca.gov/), and then enter in the three digit station identification code. Table 6-1 provides the CDEC station codes. In addition, DWR operates three of the thirteen South Delta stations in conjunction with USGS flow stations:

- Grant Line Canal near Old River
- Old River downstream of the ORT barrier
- Victoria Canal

Table 6-1: Continuous Monitoring Station Coordinates and Date of Establishment.

Station Name	Latitude	Longitude	Date Established	CDEC Code
Doughty Cut above Grant Line Canal	37º 48' 53.0"	-121º 25' 30.8"	June 19th, 2006	DGL
Grant Line Canal above the GLC barrier	37º 49' 12.7"	-121º 26' 42.1"	March 24th, 2006	----
Grant Line Canal at Tracy Blvd	37º 49' 12.4"	-121º 26' 59.4"	March 6th, 2006	GCT
Grant Line Canal near Old River	37º 49' 12.4"	-121º 32' 40.6"	February 2nd, 2007	GLC
Middle River at Howard Road	37º 52' 34.4"	-121º 22' 59.9"	October 1st, 1999	MHO
Middle River at Undine Road	37º 50' 02.2"	-121º 23' 08.6"	June 4th, 2002	----
Middle River at Union Point	37º 53' 26.8"	-121º 29' 18.1"	February 23rd, 2006	MUP
Middle River near Tracy Blvd	37º 52' 53.2"	-121º 28' 02.5"	January 1st, 2003	----
Old River at Tracy Wildlife Association	37º 48' 10.1"	-121º 27' 26.7"	July 14th, 1999	TWA
Old River downstream of the ORT barrier	37º 48' 39.5"	-121º 32' 39.9"	January 18th, 2006	ODM
Old River at Head	37º 49' 09.8"	-121º 21' 36.4"	January 1st, 2001	----
Old River upstream of the ORT barrier	37º 48' 36.9"	-121º 32' 31.9"	January 1st, 2000	OAD
Victoria Canal	37º 52' 15.5"	-121º 31' 47.9"	March 30th, 2007	VCU



Site #	Location
1	Old River at Head
2	Old River at Tracy Wildlife Association
3	Old River upstream of the ORT barrier
4	Old River downstream of the ORT barrier
5	Middle River at Undine Road
6	Middle River at Howard Road
7	Middle River near Tracy Blvd
8	Middle River at Union Point
9	Doughty Cut above Grant Line Canal
10	Grant Line Canal above the GLC barrier
11	Grant Line Canal at Tracy Blvd
12	Grant Line Canal near Old River
13	Victoria Canal

Figure 6-1: Continuous Monitoring Locations for the South Delta Temporary Barriers Project

Instrumentation

DWR collects data for the following constituents in 15 minute intervals at a 1 meter depth by deploying Yellow Spring Instrument (YSI) 6600 sondes:

- water temperature (ºC)
- dissolved oxygen (mg/L)
- pH
- specific conductance (µS/cm)
- turbidity (NTU)
- chlorophyll (µg/L)

YSI 6600 sondes are approximately two feet long and three and half inches in diameter. They are completely submersible and self-contained, operating on a minimum of 9 volts of battery power from 8 C-cell alkaline batteries. Deployment data are logged in each sonde's internal memory. Sondes are capable of sampling at many different user-specified frequencies. During 2000, DWR staff used an hourly sampling frequency for all stations, which is approximately 732 samples per month. In 2001, the sampling frequency was changed to a 15-minute interval, approximately 2,920 samples per month. The change to 15-minute intervals allows for a more in-depth review of tidal factors that influence water quality. For detailed information on YSI instrumentation visit www.ysi.com.

At each monitoring site, a sonde is vertically housed within a 4" diameter PVC pipe in the water column and suspended at a depth of approximately 1 meter. To adjust for changing tides, DWR staff installed floats to maintain the 1 meter depth. To discourage vandalism the pipes are covered at the top with an end-cap and locked with master locks through two 0.5" diameter bolts. The installation pipes have 2.25 inch diameter holes along the length of the pipe spaced approximately 8 to 10 inches on center. Four sets of holes are arranged longitudinally at 90º angles from each other. These holes allow ambient water to adequately contact the sonde sensors to ensure accurate data collection. At each site, the sonde installation pipe is either lag-bolted into an existing float structure (wooden boat dock), steel-banded to a pump platform durable enough to withstand long-term usage, or bracketed to a USGS pile.

In addition to the YSI 6600 sondes, DWR staff use three other field instruments to test the validity of the sonde data:

- YSI-63 handheld unit that measures water temperature, pH, and specific conductance
- YSI Pro-ODO Luminescent Dissolved Oxygen handheld unit to check dissolved oxygen concentrations
- HACH 2100P turbidimeter to measure turbidity

Data Collection

DWR staff clean and calibrate each sonde before deployment to ensure each probe is operating correctly before being used in the field. Calibration methods for each constituent are based on YSI's Principles of Operations. In addition, the three handheld units are calibrated regularly according to the following schedule:

- The pH probe on the YSI-63 unit and the YSI Pro-ODO dissolved oxygen unit are calibrated every time before they are used in the field.
- The specific conductance probe on the YSI-63 unit is calibrated once a month.
- The HACH 2100P turbidimeter is calibrated every three months.

During the fall and winter months, sondes are typically deployed for a three-week period, after which staff exchange it with a clean and newly calibrated sonde. DWR staff use a two-week rotational period during the warmer and more biologically productive spring and summer months to reduce biological growth on the probe surfaces. When visiting a station to exchange sondes, DWR staff measure water temperature, specific conductance, pH, dissolved oxygen, and turbidity data at a 1 meter depth with the three handheld field instruments mentioned in the above section. In addition, staff collect a chlorophyll *a* sample in a plastic quart bottle at 1 meter depth with a Van Dorn sampling device. The chlorophyll *a* sample and other field measurements are sampled at a 1 meter depth since the YSI 6600 sondes are also sampling at this depth. During each field run, DWR staff also collects a duplicate chlorophyll *a* sample at one of the stations to test for field and lab precision and repeatability.

Immediately after the chlorophyll *a* samples are collected, DWR staff store them in a cooler that contains ice to preserve the samples at 4ºC and to keep them out of the sunlight. DWR staff filter the chlorophyll *a* samples at the NCRO water quality lab by passing approximately 500 mL of sample water through a 47 mm diameter glass fiber filter with a 1.0 μm pore size at a pressure of 10 inches of mercury. After filtration, the filters are immediately frozen in a freezer and transported to DWR's Bryte Laboratory within 28 days for analysis. Bryte Laboratory uses Standard Method 10200 H (Spectrometric Determination of Chlorophyll) to analyze the chlorophyll *a* samples. The data from the chlorophyll *a* field samples are used to adjust the chlorophyll *a* concentrations measured by the sondes, which is described in a later section.

<u>Post-deployment Quality Assurance</u>

After the YSI 6600 sondes are removed from the field, DWR staff perform the following two procedures to check whether the sondes are still operating properly and measuring accurately:

- A post-deployment accuracy check on the day the sondes are removed and before the instruments are cleaned
- A comparison between the data measured by the handheld field instruments and the data collected by the sonde at the closest 15 minute time interval

The accuracy of sonde probes while deployed in the field can be negatively affected by probe malfunction, drift away from initial calibration, and/or fouling caused by biological growth on the probe reading surface. DWR staff perform the post-deployment accuracy check by the following procedure prior to cleaning the sonde probes:

1) Placing the sonde probes in fresh calibration standards with known values
2) Operating the sondes in the standards and recording the values the sondes are reading
3) Rating the values collected during the accuracy check for each constituent as excellent, good, fair, or poor based on their deviation from the calibration standard according to the USGS technical report "Guidelines and Standard Procedures for Continuous Water Quality Monitors-Station Operation, Record Computation, and Data Reporting" (Wagner et al., 2006)

The ratings obtained from the accuracy check indicate the quality, accuracy, and reliability of the data that the sonde collected while in the field.

In addition to the post-deployment accuracy check, DWR staff compare the water temperature, specific conductance, pH, dissolved oxygen, and turbidity data measured in the field by the handheld instruments (the YSI-63, YSI Pro-ODO, and HACH 2100P) to the sonde data that is closest in time. While taking the field measurements, DWR staff attempt to collect the field readings at the same depth that the sonde probes are measuring at (1 meter) and as close to the sonde pipe as possible. Since the field instruments are calibrated regularly, a large difference between the sonde and field readings could indicate inaccuracy of the sonde data during the deployment period. DWR staff consider these comparisons between the field and sonde readings and the ratings obtained from the post-deployment accuracy check while assessing data quality when entering the continuous data into the Hydstra database.

Data Quality Assurance/Quality Control (QA/QC)

DWR staff import the data files from the sondes into the NCRO Hydstra database where additional QA/QC procedures are performed. In addition to documenting the results of the quality assurance procedures discussed in the previous section, staff use the results of these procedures to flag any suspect or unreliable data. Also, any obvious outliers in the continuous dataset due to fouling or other factors are flagged as unreliable. None of the data that has been determined by DWR staff as suspect or unreliable were used in this chapter; only data that are considered reliable and of good quality were used. The reliable and good quality data in Hydstra are used to populate the Water Data Library where the data for all the continuous sites are available online at http://wdl.water.ca.gov/.

Chlorophyll *a* estimation

Chlorophylls are complex phyto-pigment molecules found in all photosynthetic organisms, including plants and phytoplankton. There are several types of chlorophyll identified by slight differences in their molecular structure and constituents. These types include chlorophyll *a*, *b*, *c*, and *d*. Chlorophyll *a* is the principal photosynthetic pigment common to all phytoplankton and is therefore used as a measurement of the primary phytoplankton biomass.

The chlorophyll probes used on the YSI 6600 sondes emit a blue light with a peak wavelength of 470 nm. The chlorophyll within the water passing by the probe absorbs this blue light from the probe and then emits or fluoresces light with a wavelength of 650-700 nm. The amount of fluorescence from the chlorophyll is then quantified by a photodetector on the probe. Currently, YSI chlorophyll probes cannot distinguish between the slight difference in fluorescence from chlorophylls *a, b, c*, and *d*, which causes inaccuracy when attempting to quantify chlorophyll *a* concentrations.

To more accurately calculate chlorophyll *a* concentrations, DWR staff take water samples in the field for chlorophyll *a* analysis at Bryte Laboratory. Laboratory analysis is the most accurate method of measuring chlorophyll *a* concentrations. This method involves extracting chlorophyll from cells and using a spectrometer which specifically measures chlorophyll *a* without interference from other chlorophyll species (*b*, *c*, or *d*).

DWR staff used the chlorophyll *a* data from the lab to adjust the YSI sonde chlorophyll data by using an equation generated from regression analysis. This was done by first matching the lab data with the corresponding sonde chlorophyll values measured closest in time. For example, the data for a chlorophyll *a* field sample collected at 9:55 am was matched with the sonde time-series value at the 15-minute time interval closest to 9:55 am, which would be at 10:00 am. If DWR staff happened to collect a duplicate field sample at this location, then the average of the two values would be used in the analysis.

In past years of this report, staff used all of the chlorophyll data collected, including those collected during earlier years, to provide a larger data set to develop a more robust regression model; however, scatterplots of the matched sonde and lab chlorophyll data indicate that at some of the stations the relationship between these two variables may have been different in 2011 when compared to the years prior. This may be due to the very wet winter and spring in Northern and Central California during 2011. In order to determine if the relationship between the sonde and lab chlorophyll data for 2011 was significantly different than the relationship between these two variables during the years prior, staff used an analysis of covariance procedure (ANCOVA). The decision process to use chlorophyll data collected prior to 2011 is as follows:

- If the ANCOVA statistical test indicated that a significant difference existed between the relationship of the 2011 data and the relationship of the earlier data, then staff only used the 2011 chlorophyll data for the regression analysis. In this case it would be inaccurate to use the data that was collected prior to 2011 since this earlier data represents conditions when the underlying relationship between the lab and sonde chlorophyll data was different.

- If the ANCOVA procedure indicated that a significant difference did not exist between the relationship of the 2011 data and the relationship of the earlier data, then staff used all of the available chlorophyll data for the regression analysis.

The results of these statistical tests are shown in Table 6-2 in the “Regression Method” column.

After all of the chlorophyll data was compiled, DWR staff then used the Minitab statistical software to analyze regression relationships for the matched chlorophyll data pairs. Each of the 13 continuous monitoring locations was analyzed individually since the relationship between lab and sonde data is specific to location. Each regression analysis generated an equation describing the relationship between sonde and lab chlorophyll data for the particular location. DWR staff then used these equations to adjust the chlorophyll concentrations from the sonde to more closely represent chlorophyll *a* concentrations. The regression analysis procedure is described in the following steps:

1) A simple linear regression analysis is performed with the sonde data as the explanatory variable (x-variable) and the laboratory data as the response variable (y-variable). Three assumptions of this parametric regression procedure are: the data follow a linear pattern, the underlying distribution of the data follows a normal or bell-shaped curve, and the variance of the residuals from the regression is constant. If these three assumptions are met, then the equation from the linear regression analysis can be used to adjust chlorophyll *a* concentrations. Next, the seasonal terms, sine and cosine, are added to the regression analysis, which is described more in step #3. If one or more of the three assumptions of parametric regression models are not met, move on to step #2.
2) If the data do not follow a linear pattern, the explanatory variable (sonde data) needs to be transformed so that this assumption is met. If the variance of the residuals is not constant or the underlying data is not normally distributed, then the response variable (laboratory data) needs to be transformed. A typical transformation that is effective for this data is the natural logarithm. Once the response variable is transformed, the regression equation no longer predicts the mean chlorophyll *a* concentration; it predicts the geometric mean or median. In order to correct for this, either of two methods can be used: the Maximum Likelihood Estimator (MLE) or Smearing. These methods are described more in Step #4. If transforming the data allows for the three assumptions of a linear regression to be met, move on to step #3 and then step #4. If it is not possible to transform the data so that the three regression assumptions are satisfied, then a nonparametric regression needs to be used, which is described in Step #5.
3) If the equation from either the simple linear regression (Step #1) or the linear regression with transformed data (Step #2) is going to be used, then the seasonal terms, sine and cosine, are added to the regression analysis to determine if they are good predictors of the seasonality of chlorophyll concentrations. If one or both of the seasonal terms are statistically significant in the analysis, then both terms are added to the regression equation in order to incorporate seasonality into the equation. If transformation was not necessary to develop the regression equation, then the model is ready to use to adjust chlorophyll *a* concentrations. However, if transformation was necessary, then the equation is ready to use with the addition of one of the bias correction methods described in step #4.
4) MLE is one of the bias correction methods used to estimate the mean concentration when using a regression equation with the response variable transformed to a natural logarithm. The MLE is calculated by the following equation:

   $$MLE = e^{(0.5*MSE)}$$

   The MSE is the mean squared error in logarithmic units, which is a quantification of the difference between the true data and the data estimated by the regression equation. The adjusted chlorophyll *a* data generated by the regression equation with a natural logarithm transformation is then corrected by multiplying the adjusted value by the MLE. For all of the stations that had a regression equation with data transformed to natural logarithms, the MLE was used as the bias correction factor to estimate the mean chlorophyll *a* concentrations. The Smearing correction factor was not used as a bias correction factor for any of the stations, since the MLE was the better estimator[2].

5) If transforming the data doesn't allow for the assumptions of a linear regression to be attained, then the Theil-Sen line, a nonparametric regression procedure, can be calculated. Like with the linear regression when the response variable is transformed to the natural logarithm, the Theil-Sen line equation predicts the median chlorophyll *a* concentration. However, there is no bias correction factor available to estimate the mean concentrations when using a nonparametric regression procedure. Therefore, when summarizing chlorophyll *a* concentrations adjusted with the Theil-Sen equation, statistics such as daily or monthly averages cannot be reliably calculated.

The regression procedures, equations, and bias correction factors used for all 13 continuous monitoring locations are provided in Table 6-2. After DWR staff generated the regression equations for each of the monitoring locations, each 15-minute chlorophyll value recorded by the sonde was adjusted by using the equation for the particular location. If the natural logarithm transformation was used for the response variable (y variable), then staff had to use the natural exponent (e) to "back-transform" each 15-minute value to convert to the correct units, and then multiply each value by the MLE to estimate the mean adjusted concentration. Staff used these adjusted chlorophyll *a* values when calculating summary statistics or when performing other statistical analyses.

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[2] The decision to use the MLE or Smearing correction factor was determined by the following procedure. The sonde chlorophyll data that was matched to the lab chlorophyll data was plugged into the regression equation and then corrected by the MLE factor to provide a predicted sonde chlorophyll concentration. These predicted values were then matched with their corresponding lab chlorophyll values, and a linear regression was performed on the matching pairs. The same procedure was used with the Smearing correction factor. The correction factor that gave a regression equation with a slope closest to one was then used.

Table 6-2: Information from Regression Analysis for the Continuous Monitoring Locations

Station Name	Regression Method	Regression Equation [a]	MLE or Smearing Correction Factor [b]
Doughty Cut above Grant Line Canal	Linear Regression of just 2011 data	Adjusted Chl = 1.380*(Sonde Chl)-1.262	----
Grant Line Canal above Barrier	Theil-Sen Line of just 2011 data	Adjusted Chl = 1.070*(Sonde Chl)-0.655	----
Grant Line Canal at Tracy Blvd	Theil-Sen Line of just 2011 data	Adjusted Chl = 1.242*(Sonde Chl)-0.455	----
Grant Line Canal near Old River	Linear Regression with Seasonality of 2007-2011 data	ln Adjusted Chl = - 0.545 - 0.242 sin(2piT) - 0.401 cos(2piT) + 1.254 ln Sonde Chl	1.145
Middle River at Howard Road	Linear Regression of just 2011 data	Adjusted Chl = 1.827*(Sonde Chl)-0.384	----
Middle River at Undine Road	Linear Regression of just 2011 data	Adjusted Chl = 1.406*(Sonde Chl)-0.215	----
Middle River at Union Point	No Equation Used [c]	No Equation Used	----
Middle River near Tracy Blvd	Linear Regression with Seasonality of 2006-2011 data	ln Adjusted Chl = 0.231 - 0.0925 sin(2piT) - 0.243 cos(2piT) + 0.180 Sonde Chl	1.112
Old River at Tracy Wildlife Association	Linear Regression with Seasonality of 2005-2011 data	ln Adjusted Chl = - 0.174 - 0.102 sin(2piT) - 0.333 cos(2piT) + 1.286 ln Sonde Chl	1.082
Old River downstream DMC Barrier	Linear Regression with Seasonality of 2006-2011 data	ln Adjusted Chl = - 1.212 - 0.214 sin(2piT) - 0.410 cos(2piT) + 1.685 ln Sonde Chl	1.131
Old River near Head	Linear Regression with Seasonality of 2005-2011 data	ln Adjusted Chl = 0.117 - 0.126 sin(2piT) - 0.331 cos(2piT) + 1.176 ln Sonde Chl	1.074
Old River upstream DMC Barrier	Linear Regression with Seasonality of 2005-2011 data	ln Adjusted Chl = - 0.111 - 0.119 sin(2piT) - 0.271 cos(2piT) + 1.092 ln Sonde Chl	1.174
Victoria Canal	No Equation Used [d]	No Equation Used	----

[a] "ln" signifies the natural logarithm function. When the seasonal terms, sin(2πT) and cos(2πT), are used "π" signifies the constant pi (3.141593) and "T" signifies decimal time.

[b] The MLE was used at all of the stations with transformed response variables (y variables).

[c] No equation was used to adjust chlorophyll concentrations because both the simple linear regression (p-value=0.32) and the Theil-Sen line (p-value=0.09) were not significant.

[d] No equation was used to adjust chlorophyll concentrations since there wasn't enough data in the higher concentration range to define the relationship. In addition, the Theil-Sen equation was not statistically significant.

Data Analysis

Staff used descriptive statistics, including monthly mean, median, maximum, minimum, and standard deviation to summarize and compare the continuous data for each constituent measured by the sondes at all 13 stations. To illustrate seasonal and annual trends, staff also calculated and graphed daily means (or medians), maximums, and mininums for each constituent at all 13 stations.

In addition to those discussed above, DWR staff performed the following analyses on the continuous data to address the preceding questions:

Question: How often did the pH and dissolved oxygen data collected at all of the stations exceed established water quality standards? Does the number of times the data exceeded the standards differ depending upon the season?

Analysis: To compare the data with established pH and dissolved oxygen water quality standards, staff calculated the number of sonde data points collected at each station that exceeded the particular standard. In addition, the analyses were separated by season[3] to determine if there were any seasonal trends. Staff also calculated the percent of samples exceeding a particular standard relative to the total number of samples collected during each season. The established water quality standards are 8.50 units for pH[4] and 5.0 mg/L for dissolved oxygen[5] (CVRWQCB, 2009; USEPA, 1986). A dissolved oxygen sample less than 5.0 mg/L or a pH sample greater than 8.50 units exceeded the standard.

Question: Do the dissolved oxygen concentrations differ between stations located along a particular water body (Old River, Middle River, and Grant Line Canal) depending upon the season?

Analysis: Staff used Kruskal-Wallis hypothesis tests and Dunn's multiple comparison procedures[6], which are nonparametric statistical analyses, to determine if the stations located along the same water body had significant differences in their dissolved oxygen concentrations. Staff placed each station into one of three water body groups, and then analyzed each water body group separately to determine if there were significant differences between the sites within the group. The continuous water quality stations were grouped in the following way:

- Old River: Old River at Head, Old River at Tracy Wildlife Association, Old River upstream of the ORT barrier, and Old River downstream of the ORT barrier
- Middle River: Middle River at Undine Road, Middle River at Howard Road, Middle River near Tracy Blvd, and Middle River at Union Point
- Grant Line Canal: Doughty Cut above Grant Line Canal, Grant Line Canal above the GLC barrier, Grant Line Canal at Tracy Blvd, and Grant Line Canal near Old River

Furthermore, staff performed these analyses separately for the spring, summer, and fall seasons (defined the same as in the water quality standard analysis) to determine if there were any seasonal

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3 Staff defined the seasons as follows: Winter (January, February, and December), Spring (March – May), Summer (June-August), Fall (September – November).

4 The Sacramento and San Joaquin River Basin Plan states that the pH should not be above 8.50 units for all water bodies without a site-specific objective (CVRWQCB, 2009).

5 The USEPA has established National Ambient Water Quality Criteria for inorganic constituents, including dissolved oxygen, to protect freshwater aquatic life. However, there is considerable variability in dissolved oxygen tolerances among fish and other aquatic life. For a warm water system like the Delta, minimum dissolved oxygen criteria for early aquatic life stages including embryos, larvae, and less than 30-day old juveniles is 5 mg/L and 3 mg/L for other life stages including older juveniles and adults (USEPA, 1986). In addition the Sacramento and San Joaquin River Basin Plan states that within the legal boundaries of the Delta, dissolved oxygen concentrations should not be reduced below 5.0 mg/L in all water bodies except for the Sacramento River below the I Street Bridge, all waters west of the Antioch Bridge, and the San Joaquin River between Turner Cut and Stockton (these Delta water bodies have site-specific water quality objectives for dissolved oxygen; CVRWQCB, 2009).

6 Staff used daily medians in these hypothesis tests since using the raw data collected every 15 minutes introduces very strong serial correlation among the data. Performing hypothesis test on strongly serial-correlated data causes the test results to be "too significant" or the p-values are too low. One way to minimize this is to take daily medians or means of the data and use those in the hypothesis test. Daily medians or means can still be serial-correlated, but much less so than data collected every 15 minutes. In this case, staff used daily medians for the nonparametric hypothesis tests since these tests are used to compare median concentrations. In addition, the median summary statistic is resistant to outliers in the data and provides a typical value for the time period summarized.

trends. The analyses were only done for these three seasons since they have the highest variability in dissolved oxygen concentrations.

Staff was also interested in whether the dissolved oxygen concentrations differ between stations along a particular water body depending upon whether the barrier was installed or not; however, it was too difficult to determine if differences were due to barrier operations or seasonality. Therefore, staff decided to do the seasonal differences analysis discussed directly above.

The 401 Water Quality Certification for the Temporary Barriers Project requires the statistical comparison of the dissolved oxygen concentrations measured upstream and downstream of the three temporary barriers on a monthly basis. For each barrier, staff used one the following nonparametric hypothesis tests to compare the upstream and downstream stations that are closest to the barrier:

- The 1-sample Wilcoxon test: This is the preferred test for this type of analysis since it is used to compare paired values, such as paired daily medians of the upstream and downstream stations. However, because this test requires data to be paired, it does not accommodate a data set with missing data.
- The Mann-Whitney test: This test is used to compare two non-paired or independent groups of data, and can be used with data sets with missing data.

Of the three temporary barriers, only the upstream and downstream stations adjacent to the Grant Line Canal Barrier had complete data records for dissolved oxygen; therefore, staff used the 1-sample Wilcoxon test to compare the paired daily medians[7] of these two stations. The Middle River near Tracy Blvd and Old River below the ORT barrier stations had 7 and 11 days without dissolved oxygen data, respectively. As a result, the Mann-Whitney test was used to compare the daily medians of the stations upstream and downstream of the Middle River Barrier and the Old River near Tracy Barrier. For all of these two-station comparisons, staff performed these analyses separately for each month during 2011.

RESULTS

The results and analyses for the South Delta continuous monitoring data from 2011 are discussed below with a separate section for each constituent collected. The monthly maximums, minimums, averages, medians and standard deviations for each constituent are summarized in Table 6-3 for the Grant Line Canal stations, Table 6-4 for the Victoria Canal station, Table 6-5 for the Middle River stations, and Table 6-6 for the Old River stations.

Water Temperature

Temperature affects pH, conductance, the solubility of constituents such as dissolved oxygen, the rate of chemical reactions, and biological activity in water (Radtke et al., 2004). It is also probably the single most important factor affecting fish distribution both between and within estuaries seasonally, although temperature effects are closely tied to the effects of other variables (Moyle and Cech, 2000).

During 2011, the highest water temperature at the South Delta continuous monitoring stations was 27.3°C (81.1ºF) on July 8th at Middle River near Tracy Blvd, and the lowest was of 5.1°C (41.2ºF) on December 26th at Middle River at Howard Road (Tables 6-3 to 6-6). Figures 6-2, 6-3, and 6-4 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively. Temperature patterns followed seasonal trends, with the highest temperatures occurring in summer and the lowest in winter. Monthly mean temperatures in the summer (June – August) ranged from 17.9ºC (64.2ºF) in June at Old River at Head to 24.0ºC (75.2ºF) at three stations in July and August (Tables 6-3 to 6-6). In the winter (January – February, and December), monthly mean temperatures ranged from 7.4ºC (45.3ºF) in December at Middle River at

[7] Staff used the daily medians in the hypothesis tests to minimize the effects of serial correlation. This issue is described in more detail on the previous page in footnote number 6.

Howard Road to 10.4ºC (50.7ºF) in February at six stations. Water temperatures in spring and fall exhibited the steepest increases and decreases in temperature in accordance with seasonal temperature changes. Overall mean temperatures for the 2011 monitoring period ranged from 15.0°C (59.0ºF) at both Old River at Head and Middle River at Undine Road to 16.6°C (61.9ºF) at Middle River at Union Point.

Table 6-3: Monthly Statistics for the Grant Line Canal continuous water quality monitoring stations

Month	Water Temperature (°C)				Dissolved Oxygen (mg/L)				pH			
	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	10.7	10.7	10.6	10.5	10.43	10.53	10.21	10.20	7.65	7.61	7.98	7.50
February	11.9	11.4	11.5	11.7	11.05	11.07	10.99	10.94	7.91	7.57	8.01	7.67
March	15.5	15.3	15.4	15.7	10.77	10.59	10.55	10.71	7.83	7.62	7.69	7.70
April	16.9	16.9	16.9	17.1	9.61	9.58	9.51	9.45	8.39	7.35	7.69	7.35
May	18.8	18.7	18.8	18.6	9.72	9.81	9.67	9.82	7.93	7.51	7.61	7.64
June	21.5	21.5	21.5	22.7	9.83	9.77	9.69	9.98	7.64	7.74	7.79	7.67
July	24.1	23.7	23.7	24.5	11.42	11.51	11.43	10.44	8.49	8.47	8.27	8.07
August	22.7	23.5	22.4	24.4	11.96	13.98	12.49	10.45	8.66	8.96	8.63	8.17
September	22.2	22.8	22.2	23.8	10.47	10.01	10.18	9.23	8.20	8.21	8.07	7.73
October	19.1	19.4	19.3	22.0	9.80	9.59	9.51	9.85	8.00	7.96	7.84	7.61
November	15.1	15.0	15.0	16.3	10.41	10.10	10.26	10.50	7.86	7.95	7.80	7.86
December	11.4	11.4	11.4	11.4	12.80	13.04	12.96	12.56	8.26	8.43	7.96	8.14
	AVERAGES				AVERAGES				AVERAGES			
January	9.4	9.4	9.4	9.3	9.90	9.81	9.77	9.66	7.47	7.40	7.44	7.26
February	10.4	10.3	10.4	10.4	10.58	10.44	10.44	10.36	7.61	7.40	7.69	7.52
March	12.2	12.2	12.3	12.3	9.94	9.86	9.71	9.62	7.52	7.38	7.29	7.47
April	15.3	15.3	15.4	15.4	8.59	8.53	8.43	8.37	7.89	7.18	7.31	7.16
May	16.4	16.3	16.3	16.4	8.71	9.24	9.12	8.97	7.51	7.33	7.50	7.38
June	18.2	18.1	18.2	18.4	9.16	9.13	9.11	8.89	7.44	7.27	7.50	7.42
July	21.1	21.1	21.1	21.6	8.88	8.75	8.86	8.10	7.43	7.30	7.48	7.35
August	20.0	20.2	20.1	21.4	9.72	9.52	9.81	8.16	7.72	7.74	7.82	7.36
September	20.0	20.2	20.1	20.9	9.06	8.67	8.88	7.69	7.49	7.73	7.63	7.38
October	16.6	16.6	16.7	17.2	9.01	8.75	8.86	8.35	7.59	7.71	7.43	7.22
November	12.6	12.6	12.6	12.8	9.58	9.49	9.49	9.50	7.71	7.79	7.61	7.36
December	8.5	8.6	8.6	8.5	11.20	11.13	11.19	11.02	7.88	7.87	7.54	7.80
	MEDIANS				MEDIANS				MEDIANS			
January	9.6	9.5	9.5	9.5	9.92	9.84	9.79	9.72	7.51	7.44	7.85	7.27
February	10.3	10.3	10.3	10.3	10.56	10.46	10.43	10.36	7.71	7.39	7.68	7.54
March	12.4	12.4	12.4	12.5	10.20	10.12	9.92	9.77	7.62	7.45	7.49	7.56
April	15.4	15.4	15.5	15.5	8.69	8.57	8.48	8.40	8.11	7.19	7.40	7.16
May	16.4	16.3	16.4	16.3	9.19	9.29	9.17	8.99	7.52	7.38	7.50	7.40
June	18.3	18.3	18.3	18.7	9.29	9.25	9.25	8.98	7.44	7.41	7.48	7.44
July	21.0	21.0	21.0	21.4	8.71	8.57	8.62	8.11	7.42	7.39	7.46	7.36
August	19.9	20.0	19.9	21.1	9.68	9.46	9.76	8.08	7.87	7.79	7.87	7.36
September	19.9	20.0	20.0	20.9	8.99	8.57	8.75	7.64	7.65	7.78	7.69	7.38
October	16.8	16.9	16.9	17.3	8.95	8.67	8.81	8.29	7.63	7.69	7.41	7.37
November	12.7	12.6	12.7	12.7	9.58	9.48	9.46	9.49	7.71	7.79	7.67	7.60
December	8.5	8.6	8.6	8.5	11.00	10.94	11.02	10.90	7.86	7.92	7.50	7.84
	MINIMUMS				MINIMUMS				MINIMUMS			
January	7.5	7.5	7.5	7.5	9.43	9.18	9.31	8.92	7.21	7.10	7.03	7.05
February	9.3	9.3	9.3	9.5	10.24	9.91	10.00	9.79	7.36	7.30	7.50	7.27
March	9.8	9.7	9.8	9.9	7.40	7.39	7.24	7.11	7.07	7.04	6.90	7.06
April	13.7	13.8	13.8	13.7	7.04	7.08	6.92	6.81	7.06	6.96	6.78	7.03
May	14.1	14.0	14.1	14.3	6.55	8.48	8.43	5.35	7.27	7.11	7.37	7.11
June	14.6	14.6	14.6	14.6	7.07	7.18	7.40	6.00	7.24	6.85	7.27	7.02
July	18.9	18.9	18.9	19.1	6.63	6.30	7.42	6.12	7.11	6.76	7.23	6.97
August	18.9	18.8	18.8	19.2	8.29	7.62	8.29	5.71	7.19	7.34	7.45	7.01
September	18.3	18.4	18.5	19.1	8.20	7.21	7.76	6.63	6.96	7.36	7.35	7.15
October	14.3	14.3	14.4	14.2	8.01	6.86	7.71	6.74	7.37	7.54	7.17	6.89
November	11.4	11.3	11.4	11.3	8.68	8.65	8.13	8.88	7.56	7.65	7.20	6.96
December	6.7	6.6	6.8	6.8	10.04	8.73	10.05	10.01	7.75	7.57	7.40	7.45
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	0.8	0.8	0.8	0.8	0.24	0.29	0.21	0.28	0.10	0.11	0.38	0.08
February	0.5	0.5	0.5	0.5	0.19	0.23	0.23	0.21	0.16	0.05	0.10	0.08
March	1.2	1.2	1.2	1.2	0.73	0.70	0.70	0.71	0.18	0.14	0.25	0.16
April	0.8	0.8	0.8	0.8	0.74	0.63	0.64	0.66	0.30	0.09	0.23	0.08
May	1.0	1.0	1.0	0.9	0.87	0.27	0.29	0.37	0.15	0.10	0.04	0.11
June	2.0	1.9	2.0	2.0	0.45	0.41	0.37	0.53	0.07	0.26	0.10	0.10
July	1.0	1.0	1.0	1.2	0.73	0.72	0.78	0.53	0.29	0.35	0.20	0.14
August	0.7	0.8	0.7	1.2	0.74	0.83	0.80	0.69	0.35	0.29	0.24	0.15
September	0.8	0.8	0.8	1.0	0.47	0.43	0.40	0.38	0.31	0.17	0.18	0.10
October	1.1	1.1	1.1	1.4	0.27	0.37	0.28	0.43	0.14	0.08	0.15	0.21
November	0.8	0.8	0.8	0.8	0.21	0.20	0.22	0.24	0.04	0.05	0.12	0.29
December	0.9	0.9	0.9	0.9	0.57	0.68	0.56	0.50	0.10	0.21	0.13	0.12
2011 - Max.	24.1	23.7	23.7	24.5	12.80	13.98	12.96	12.56	8.66	8.96	8.63	8.17
2011 - Avg.	15.1	15.1	15.1	15.4	9.55	9.44	9.47	9.05	7.58	7.45	7.49	7.36
2011 - Med.	15.5	15.4	15.5	15.6	9.52	9.40	9.39	9.08	7.64	7.50	7.54	7.40
2011 - Min.	6.7	6.6	6.8	6.8	6.55	6.30	6.92	5.35	6.96	6.76	6.78	6.89
2011 - S.D.	4.3	4.3	4.3	4.7	0.94	0.91	0.90	1.08	0.27	0.30	0.24	0.21

Table 6-3 (continued): Monthly Statistics for the Grant Line Canal continuous water quality monitoring stations

Month	Specific Conductance (µS/cm)				Turbidity (NTU)				Chlorophyll (µg/L)			
	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	312	308	317	316	64.2	85.2	67.5	88.7	7.6	6.2	9.7	6.4
February	344	332	331	341	42.6	74.8	44.1	59.9	8.4	20.5	18.2	6.2
March	359	359	362	364	85.6	89.0	79.9	77.3	10.7	8.5	11.7	25.1
April	208	202	199	204	54.3	76.4	41.8	63.2	20.5	12.4	13.6	39.4
May	232	214	213	222	61.0	79.6	40.5	81.1	13.4	14.9	12.6	18.8
June	242	206	221	235	53.2	72.8	42.1	74.7	20.4	30.7	26.2	20.9
July	422	439	419	437	52.7	69.9	66.7	78.3	34.6	36.0	23.5	36.6
August	434	426	419	433	36.3	63.4	34.6	44.6	34.3	33.6	40.8	39.2
September	463	466	462	464	39.1	34.9	53.5	30.2	19.0	18.0	15.7	7.6
October	333	320	329	313	44.8	61.5	69.2	42.1	12.4	9.0	10.0	4.1
November	723	702	711	708	40.2	45.0	45.5	31.4	10.9	21.9	7.6	13.1
December	864	849	868	826	59.7	46.3	31.9	25.2	27.6	41.8	34.6	34.3
	AVERAGES				AVERAGES				AVERAGES			
January	228	226	228	234	29.7	29.6	27.8	25.4	3.2	--	--	2.4
February	278	278	280	283	19.1	17.2	15.8	13.7	3.5	--	--	2.1
March	270	268	267	269	25.4	23.6	23.2	20.9	6.1	--	--	2.7
April	160	161	162	164	22.3	21.2	17.6	19.8	8.1	--	--	3.4
May	176	173	173	176	17.2	20.0	18.2	15.7	6.2	--	--	4.2
June	175	169	169	174	25.1	20.1	18.7	18.5	8.3	--	--	7.8
July	222	219	215	208	23.9	19.7	21.3	20.9	13.0	--	--	11.2
August	260	259	259	264	17.7	14.4	15.0	16.4	13.0	--	--	7.0
September	310	314	313	302	17.3	14.3	14.6	11.6	8.7	--	--	2.4
October	267	266	266	259	15.4	12.4	13.6	8.7	4.4	--	--	1.7
November	540	554	560	453	11.0	7.7	8.1	5.7	3.1	--	--	1.9
December	772	793	796	684	7.8	5.6	5.5	4.1	7.5	--	--	3.3
	MEDIANS				MEDIANS				MEDIANS			
January	224	223	224	232	28.0	27.2	26.0	23.0	2.9	3.2	3.0	1.9
February	273	275	277	279	16.3	14.9	13.8	12.0	3.3	3.7	4.5	1.8
March	267	272	269	274	16.6	14.5	16.2	15.0	5.9	2.8	5.4	2.5
April	151	153	154	157	22.3	19.2	16.2	18.1	7.4	3.5	5.4	3.0
May	176	169	169	173	12.2	20.0	18.5	14.9	5.6	5.7	6.9	4.0
June	178	176	173	177	24.8	19.5	18.3	16.6	8.4	5.9	7.1	7.4
July	190	184	182	178	22.9	18.1	19.1	19.8	11.2	7.5	10.1	11.0
August	261	262	261	261	17.7	14.3	14.9	16.2	11.8	7.9	10.8	5.4
September	320	321	319	306	17.3	14.1	14.4	11.2	8.8	3.4	7.5	2.3
October	270	273	273	262	15.4	11.6	12.6	8.4	4.1	1.5	2.8	1.7
November	575	594	600	504	10.4	6.9	7.2	5.1	3.0	1.6	2.9	1.8
December	782	804	804	786	7.2	4.8	5.3	3.8	6.2	4.6	7.0	2.0
	MINIMUMS				MINIMUMS				MINIMUMS			
January	153	158	155	165	11.3	9.8	8.0	6.1	0.9	1.6	1.0	0.6
February	218	215	217	220	9.5	6.6	6.1	4.2	1.4	1.3	0.8	0.6
March	182	178	177	178	6.3	3.3	6.5	4.4	2.5	0.6	2.7	0.7
April	139	140	142	144	8.7	14.8	11.3	10.8	1.4	1.4	3.3	0.1
May	145	142	144	145	7.5	7.7	9.0	5.1	1.5	3.0	4.1	0.0
June	129	126	126	129	10.6	6.7	7.5	8.2	3.6	2.1	3.3	2.7
July	116	112	111	116	12.5	5.9	10.3	8.9	4.1	3.0	3.9	3.6
August	154	153	153	161	10.6	5.7	7.5	5.7	1.9	1.6	0.8	0.5
September	183	179	180	183	10.6	6.8	8.0	2.0	1.8	0.4	2.7	0.3
October	209	203	203	188	6.4	4.8	7.6	2.2	1.4	0.0	0.0	0.3
November	264	270	271	184	5.3	3.0	3.8	1.9	1.2	0.0	0.4	0.6
December	670	685	689	245	4.3	2.3	2.8	1.2	0.9	1.4	2.0	0.6
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	39	37	38	36	11.7	13.1	12.1	13.3	1.1	0.9	2.0	1.2
February	25	24	24	24	6.7	7.6	6.9	7.3	1.2	1.2	1.9	1.0
March	51	52	52	51	16.4	16.7	14.5	14.5	1.5	1.0	1.8	1.1
April	17	19	17	16	8.3	5.9	4.8	6.6	4.1	1.3	2.6	2.1
May	19	19	18	19	8.9	6.0	3.6	5.2	2.7	1.1	1.5	2.1
June	20	22	22	22	5.9	6.6	5.2	6.7	2.1	2.2	2.3	2.0
July	101	106	102	94	5.0	6.9	6.9	6.3	5.8	3.1	3.4	3.9
August	60	64	61	62	2.2	3.4	2.2	4.4	7.0	4.8	8.5	4.7
September	64	66	65	67	2.2	2.9	2.3	3.4	4.0	1.5	2.5	1.2
October	25	26	27	30	3.1	4.6	4.6	3.3	1.8	0.7	1.7	0.5
November	118	116	118	169	3.4	3.5	3.8	2.6	1.0	0.9	0.8	0.6
December	40	32	32	180	3.2	3.2	1.3	1.9	4.7	3.6	5.4	3.6
2011 - Max.	864	849	868	826	85.6	89.0	79.9	88.7	34.6	41.8	40.8	39.4
2011 - Avg.	305	307	308	290	19.3	17.1	16.7	15.1	7.1	--	--	4.2
2011 - Med.	254	256	257	245	17.5	15.1	15.0	13.7	5.6	3.9	5.9	2.8
2011 - Min.	116	112	111	116	4.3	2.3	2.8	1.2	0.9	0.0	0.0	0.0
2011 - S.D.	182	187	188	164	9.8	10.2	9.0	9.7	4.9	3.3	4.5	3.7

Table 6-4: Monthly Statistics for the Victoria Canal water quality monitoring station

Month	Water Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductance (µS/cm)	Turbidity (NTU)	Chlorophyll (µg/L)
	MAXIMUMS					
January	10.1	10.18	7.94	360	40.2	13.0
February	12.0	11.06	7.81	381	38.7	7.3
March	15.8	11.06	7.79	403	35.5	30.0
April	17.7	9.85	7.66	282	31.6	21.3
May	19.4	9.75	7.73	259	37.1	13.7
June	25.1	9.08	7.66	297	36.6	18.2
July	26.6	7.78	7.29	233	31.8	28.7
August	25.4	7.94	7.56	295	33.9	36.2
September	24.4	7.85	7.58	312	47.2	23.7
October	22.3	8.58	7.62	304	31.4	17.0
November	17.6	10.24	7.81	277	51.2	27.4
December	11.4	10.95	7.65	465	37.2	27.0
	AVERAGES					
January	9.0	9.34	7.45	278	9.7	4.6
February	10.3	10.33	7.56	319	6.2	3.7
March	12.7	9.70	7.52	318	10.1	3.8
April	15.8	8.46	7.33	179	10.4	4.6
May	16.9	8.91	7.41	193	9.0	3.2
June	21.3	7.62	7.30	236	8.1	3.3
July	24.0	6.84	7.03	186	10.4	3.9
August	23.9	7.06	7.29	237	6.9	3.7
September	22.9	7.12	7.25	238	6.1	3.3
October	19.2	7.77	7.36	232	3.2	2.0
November	13.5	9.38	7.51	216	2.3	2.2
December	8.9	10.48	7.48	298	3.6	3.3
	MEDIANS					
January	9.0	9.27	7.39	277	10.0	4.7
February	10.2	10.28	7.55	318	5.7	3.7
March	12.5	9.87	7.50	337	6.2	3.2
April	15.9	8.57	7.34	175	9.7	4.0
May	16.8	8.93	7.42	193	8.9	3.2
June	22.3	7.58	7.30	237	7.6	3.3
July	24.0	6.85	7.06	185	9.5	3.8
August	23.9	7.08	7.27	236	6.1	3.8
September	23.0	7.15	7.26	232	5.3	3.3
October	19.2	7.80	7.44	231	2.5	1.8
November	13.4	9.42	7.62	213	1.8	2.0
December	9.0	10.45	7.51	278	3.1	3.2
	MINIMUMS					
January	7.6	8.98	7.25	238	4.7	2.8
February	9.4	9.60	7.37	278	3.6	2.0
March	10.1	7.08	7.29	197	2.9	1.3
April	13.9	6.63	7.13	144	5.6	2.4
May	15.1	7.44	7.16	153	5.2	1.7
June	17.1	5.39	7.10	193	3.9	1.0
July	21.7	2.09	6.75	155	5.0	2.0
August	22.2	4.09	7.06	199	2.2	0.0
September	21.6	4.35	6.94	206	2.1	0.9
October	16.9	5.88	7.10	204	0.8	0.7
November	11.4	6.59	7.13	186	0.9	0.5
December	7.0	9.94	7.28	234	1.4	1.6
	STANDARD DEVIATIONS					
January	0.6	0.26	0.19	18	2.9	0.7
February	0.5	0.24	0.07	23	1.9	0.6
March	1.3	0.67	0.11	49	7.6	1.7
April	0.9	0.69	0.10	20	3.0	1.6
May	0.8	0.34	0.11	21	1.8	0.7
June	2.3	0.68	0.11	20	2.6	1.0
July	0.9	0.42	0.10	12	3.4	0.8
August	0.5	0.29	0.11	12	3.0	2.1
September	0.5	0.31	0.10	20	3.5	1.0
October	1.1	0.38	0.14	17	2.1	0.6
November	1.4	0.42	0.16	17	2.9	1.2
December	1.0	0.18	0.10	53	2.1	1.1
2011 - Max.	26.6	11.06	7.94	465	51.2	36.2
2011 - Avg.	16.5	8.58	7.35	244	7.4	3.5
2011 - Med.	16.4	8.73	7.39	235	6.8	3.4
2011 - Min.	7.0	2.09	6.75	144	0.8	0.0
2011 - S.D.	5.6	1.31	0.19	54	4.4	1.4

Table 6-5: Monthly Statistics for the Middle River continuous water quality monitoring stations

	Water Temperature (°C)				Dissolved Oxygen (mg/L)				pH			
Month	Undine	Howard	Tracy Blvd	Union Point	Undine	Howard	Tracy Blvd	Union Point	Undine	Howard	Tracy Blvd	Union Point
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	10.8	10.9	11.0	10.5	10.53	10.52	10.95	10.84	7.52	7.52	7.80	7.66
February	12.1	12.3	12.8	12.1	11.38	11.83	12.16	12.19	7.64	7.78	8.13	8.09
March	15.4	16.0	17.0	16.5	10.85	11.28	12.35	11.54	7.77	7.98	8.61	8.08
April	17.4	17.5	18.6	18.0	9.06	9.83	12.15	10.30	7.20	7.59	8.40	7.80
May	19.0	19.4	20.2	20.1	9.80	10.25	10.24	9.78	7.79	8.05	7.80	7.70
June	21.9	23.1	26.1	25.8	9.90	10.54	10.20	9.45	7.83	7.89	7.79	7.57
July	24.1	25.5	27.3	26.6	12.66	10.28	8.21	7.99	8.83	8.06	7.31	7.27
August	22.9	24.3	26.2	25.9	12.73	11.46	7.24	8.41	8.88	8.47	7.31	7.68
September	23.2	23.5	24.6	24.4	11.50	9.93	6.96	8.37	8.48	7.75	7.23	7.81
October	19.6	20.1	22.0	22.3	10.21	10.63	7.92	8.63	8.01	7.94	7.34	7.58
November	15.3	15.9	17.3	17.5	11.01	13.13	10.37	10.21	8.03	8.68	7.86	7.61
December	10.9	10.5	11.0	11.3	15.37	15.96	11.70	11.00	8.67	8.43	7.90	7.87
	AVERAGES				AVERAGES				AVERAGES			
January	10.8	10.9	11.0	10.5	10.53	10.52	10.95	10.84	7.52	7.52	7.80	7.66
February	12.1	12.3	12.8	12.1	11.38	11.83	12.16	12.19	7.64	7.78	8.13	8.09
March	15.4	16.0	17.0	16.5	10.85	11.28	12.35	11.54	7.77	7.98	8.61	8.08
April	17.4	17.5	18.6	18.0	9.06	9.83	12.15	10.30	7.20	7.59	8.40	7.80
May	19.0	19.4	20.2	20.1	9.80	10.25	10.24	9.78	7.79	8.05	7.80	7.70
June	21.9	23.1	26.1	25.8	9.90	10.54	10.20	9.45	7.83	7.89	7.79	7.57
July	24.1	25.5	27.3	26.6	12.66	10.28	8.21	7.99	8.83	8.06	7.31	7.27
August	22.9	24.3	26.2	25.9	12.73	11.46	7.24	8.41	8.88	8.47	7.31	7.68
September	23.2	23.5	24.6	24.4	11.50	9.93	6.96	8.37	8.48	7.75	7.23	7.81
October	19.6	20.1	22.0	22.3	10.21	10.63	7.92	8.63	8.01	7.94	7.34	7.58
November	15.3	15.9	17.3	17.5	11.01	13.13	10.37	10.21	8.03	8.68	7.86	7.61
December	10.9	10.5	11.0	11.3	15.37	15.96	11.70	11.00	8.67	8.43	7.90	7.87
	MEDIANS				MEDIANS				MEDIANS			
January	9.5	9.4	9.3	9.2	9.87	9.93	9.82	9.39	7.23	7.39	7.66	7.41
February	10.3	10.3	10.2	10.3	10.56	10.39	10.55	10.35	7.38	7.42	7.70	7.61
March	12.4	12.4	12.9	12.6	9.90	9.93	9.85	9.80	7.51	7.57	7.72	7.58
April	15.5	15.4	15.8	16.0	7.23	8.48	8.55	8.63	6.99	7.35	7.19	7.20
May	16.4	16.4	17.2	17.1	9.26	9.02	8.60	8.78	7.58	7.55	7.26	7.42
June	18.3	18.9	21.4	22.1	9.32	9.07	7.75	7.71	7.61	7.45	7.15	7.16
July	20.9	21.9	23.8	23.9	8.63	7.99	6.06	6.86	7.23	7.33	6.92	7.01
August	19.7	21.3	23.9	24.0	9.48	8.27	4.35	7.10	7.79	7.51	6.97	7.25
September	19.8	21.0	22.6	22.9	8.88	8.10	3.52	7.23	7.71	7.41	6.89	7.35
October	16.7	17.2	18.3	19.1	8.84	8.73	6.13	7.78	7.43	7.49	7.10	7.38
November	12.1	12.2	12.6	13.4	9.31	10.21	8.95	9.36	7.67	8.00	7.59	7.38
December	8.2	7.4	8.2	8.9	11.48	11.19	10.63	10.11	8.00	7.84	7.66	7.65
	MINIMUMS				MINIMUMS				MINIMUMS			
January	7.5	7.4	7.0	7.4	9.27	9.47	8.76	8.59	7.03	7.14	7.23	7.19
February	9.1	8.7	8.2	9.1	10.17	9.42	8.45	9.86	7.26	7.13	7.44	7.39
March	9.8	9.5	9.5	9.9	5.46	7.40	7.00	7.27	6.94	7.27	7.24	7.03
April	13.9	13.6	13.0	13.3	4.97	6.38	6.53	6.82	6.74	7.15	6.88	6.90
May	13.9	13.9	14.3	15.0	7.79	8.20	6.11	7.30	7.01	7.21	6.96	7.14
June	14.5	14.4	15.6	16.4	8.03	6.53	4.67	5.85	7.14	7.03	6.83	6.90
July	18.6	18.7	19.6	21.5	7.55	4.74	3.16	4.73	6.98	7.05	6.59	6.77
August	18.4	18.4	21.7	22.6	8.46	5.51	1.37	3.53	7.22	6.98	6.76	6.82
September	18.3	18.0	20.5	21.5	8.01	5.80	1.29	3.67	7.20	7.00	6.73	6.83
October	13.3	14.3	15.3	16.8	6.56	7.07	2.13	4.60	7.21	6.93	6.77	7.02
November	10.4	10.6	10.7	11.2	6.98	6.01	4.92	7.40	7.35	7.42	7.17	7.15
December	5.6	5.1	5.7	6.7	7.94	9.55	9.13	8.32	7.59	7.37	7.53	7.45
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	0.8	0.8	0.9	0.7	0.33	0.19	0.33	0.44	0.11	0.06	0.11	0.09
February	0.6	0.8	0.8	0.5	0.25	0.36	0.57	0.39	0.07	0.09	0.15	0.10
March	1.2	1.3	1.5	1.3	1.27	0.77	0.95	0.71	0.17	0.16	0.23	0.17
April	0.8	0.9	1.2	1.0	1.03	0.65	0.98	0.77	0.10	0.11	0.20	0.18
May	1.0	1.2	1.1	0.9	0.35	0.41	0.68	0.42	0.25	0.09	0.14	0.11
June	2.0	2.3	2.5	2.5	0.42	0.64	1.17	0.70	0.16	0.14	0.16	0.13
July	1.1	1.5	1.6	0.9	0.85	0.79	1.05	0.45	0.39	0.15	0.14	0.10
August	0.8	1.4	0.9	0.5	0.87	0.91	1.18	0.52	0.39	0.24	0.10	0.13
September	0.9	1.2	0.8	0.5	0.67	0.75	1.03	0.55	0.27	0.16	0.09	0.21
October	1.3	1.4	1.3	1.0	0.45	0.65	1.07	0.55	0.15	0.19	0.12	0.10
November	0.9	0.9	1.2	1.3	0.62	0.91	0.76	0.44	0.13	0.23	0.17	0.06
December	1.0	1.0	0.9	1.0	1.27	1.14	0.39	0.27	0.20	0.27	0.05	0.06
2011 - Max.	24.1	25.5	27.3	26.6	15.37	15.96	12.35	12.19	8.88	8.68	8.61	8.09
2011 - Avg.	15.0	15.3	16.5	16.6	9.39	9.31	7.79	8.56	7.40	7.47	7.19	7.32
2011 - Med.	15.5	15.6	16.5	16.7	9.35	9.22	8.34	8.65	7.50	7.48	7.26	7.38
2011 - Min.	5.6	5.1	5.7	6.7	4.97	4.74	1.29	3.53	6.74	6.93	6.59	6.77
2011 - S.D.	4.4	4.9	5.5	5.6	1.30	1.28	2.42	1.33	0.35	0.26	0.34	0.22

Table 6-5 (continued): Monthly Statistics for the Middle River continuous water quality monitoring stations

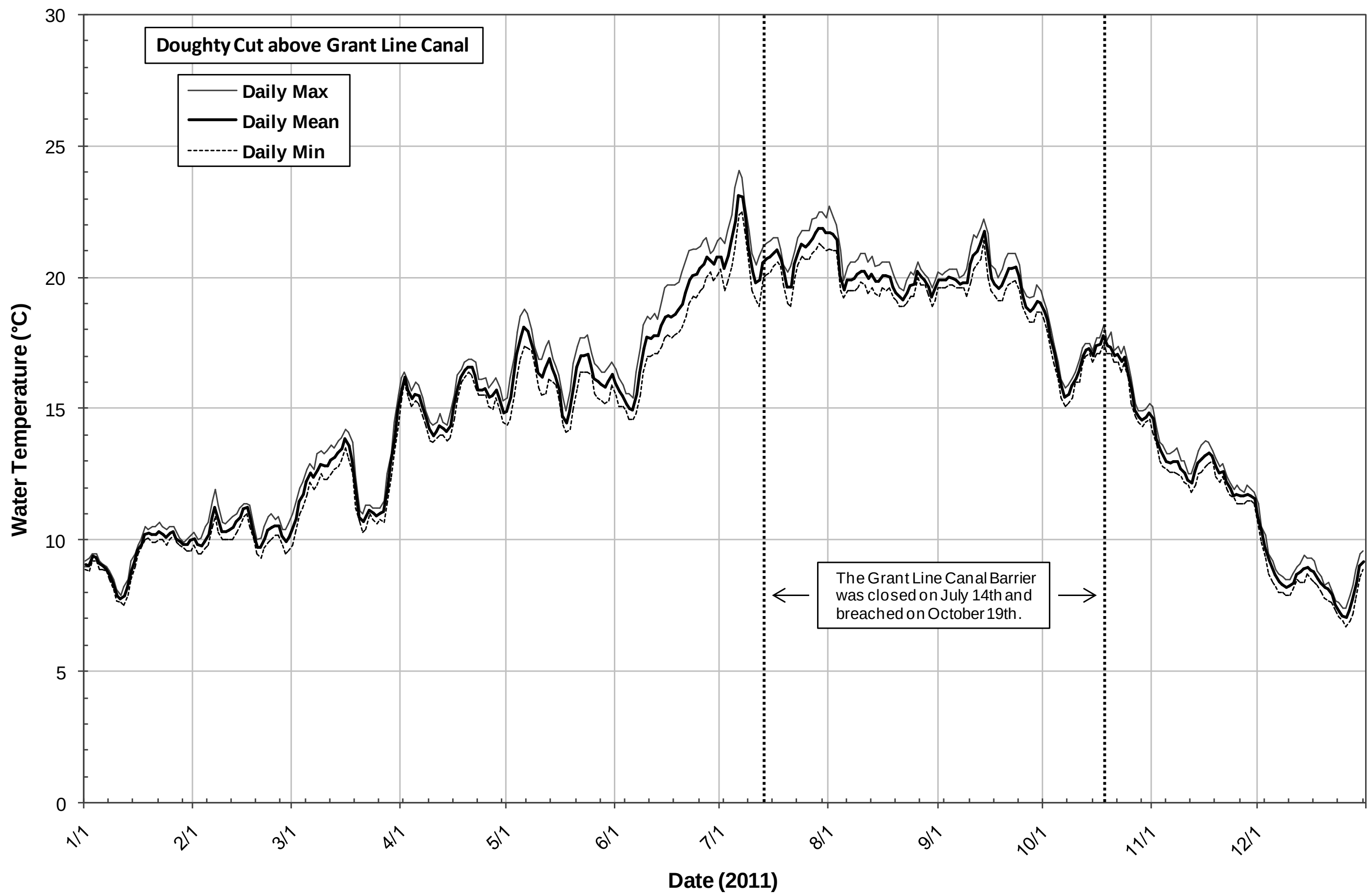
	Specific Conductance (µS/cm)				Turbidity (NTU)				Chlorophyll (µg/L)			
Month	Undine	Howard	Tracy Blvd	Union Point	Undine	Howard	Tracy Blvd	Union Point	Undine	Howard	Tracy Blvd	Union Point
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	315	578	506	455	65.5	53.6	49.1	38.2	10.9	12.4	7.3	23.5
February	555	689	535	463	43.7	48.7	28.3	26.7	16.0	16.2	5.3	16.2
March	410	478	490	461	60.9	78.4	83.4	63.9	16.2	17.2	13.7	33.2
April	193	231	306	299	15.8	43.0	54.0	49.0	10.2	30.1	11.2	34.3
May	265	327	327	330	43.8	50.4	48.5	55.1	15.5	21.7	4.3	24.7
June	270	377	312	314	43.0	54.8	48.9	46.4	13.6	19.0	55.4	21.9
July	472	719	356	286	68.2	74.2	49.6	67.6	46.2	35.1	28.0	26.9
August	417	731	458	362	65.3	61.2	31.6	55.9	60.4	28.7	6.1	27.4
September	470	626	511	334	38.2	40.3	52.1	37.6	24.2	19.7	12.2	31.2
October	314	607	409	324	33.9	22.0	57.8	25.3	13.6	15.0	5.8	27.0
November	709	951	619	403	36.6	15.4	38.5	38.2	19.0	20.6	3.1	19.8
December	1424	1090	606	430	35.1	31.4	52.6	46.5	40.7	27.0	14.8	25.3
	AVERAGES				AVERAGES				AVERAGES			
January	232	277	330	284	26.4	24.2	13.9	10.8	4.8	6.8	2.1	3.7
February	312	343	392	331	16.4	13.6	6.7	6.7	5.2	5.6	1.7	3.5
March	284	301	338	320	19.0	22.9	12.1	10.4	7.2	7.3	2.3	3.9
April	159	169	189	191	6.5	20.5	13.8	12.2	4.5	9.3	2.9	5.2
May	173	199	250	227	19.4	26.7	14.9	10.5	9.5	14.2	2.7	2.4
June	174	194	259	232	21.2	24.0	13.1	8.5	8.8	12.0	3.5	3.5
July	222	245	230	183	23.9	33.3	18.7	9.5	14.8	14.0	4.3	3.5
August	257	304	325	234	18.7	28.7	13.6	4.8	11.6	8.0	3.8	3.1
September	311	346	373	234	14.8	18.5	11.3	4.1	9.6	6.8	2.9	3.2
October	259	276	322	235	10.4	8.3	14.8	3.2	4.4	3.3	2.1	2.8
November	545	562	347	224	5.7	3.6	5.6	3.1	2.9	2.9	1.7	2.0
December	779	589	331	301	4.2	5.6	7.4	4.0	5.0	7.4	2.2	3.4
	MEDIANS				MEDIANS				MEDIANS			
January	232	267	326	274	24.1	22.5	12.5	10.0	4.3	6.7	2.0	3.6
February	317	335	387	326	13.6	10.5	5.3	6.1	4.0	4.5	1.6	2.9
March	279	305	354	327	15.8	15.0	7.5	6.5	7.0	7.1	1.9	3.8
April	149	162	182	186	5.7	19.8	13.1	11.7	4.4	8.6	2.5	4.5
May	173	196	253	228	19.6	26.1	13.9	9.7	9.5	13.9	2.7	2.0
June	179	195	262	231	21.0	23.9	12.4	8.0	8.5	11.7	3.3	3.6
July	186	196	222	180	23.8	33.5	18.1	8.8	12.7	13.0	4.0	3.5
August	260	299	321	230	18.3	28.5	12.8	4.5	8.8	7.1	3.8	3.1
September	316	341	393	227	15.0	17.6	10.0	3.9	9.1	7.8	2.6	3.1
October	263	278	323	236	9.9	7.4	12.8	2.6	4.0	2.5	2.1	2.8
November	584	610	336	219	5.3	3.5	4.6	2.6	2.9	2.9	1.7	1.7
December	790	513	315	284	3.7	4.6	6.0	3.4	3.6	3.8	2.2	2.9
	MINIMUMS				MINIMUMS				MINIMUMS			
January	156	168	226	235	9.0	7.2	4.8	5.0	1.6	2.0	1.2	1.1
February	227	233	287	277	8.1	4.6	2.9	3.4	1.3	1.3	1.2	0.6
March	187	185	201	201	7.4	4.3	3.2	2.9	4.0	2.4	1.4	1.2
April	138	142	153	152	2.4	4.7	7.2	5.6	0.9	3.3	1.9	2.0
May	139	147	173	160	7.6	17.5	6.3	5.2	3.9	8.6	2.1	0.4
June	122	128	191	186	12.3	9.7	6.4	3.4	4.1	5.5	2.2	0.8
July	108	120	150	152	11.9	6.2	6.8	2.0	6.1	6.0	2.9	1.2
August	148	161	212	193	10.6	12.5	4.7	1.4	4.1	2.0	2.7	1.5
September	173	192	238	204	6.0	8.5	4.2	1.4	2.7	0.0	1.9	1.4
October	197	198	223	201	3.9	2.7	1.7	0.3	0.6	0.3	1.5	0.5
November	264	269	203	183	2.4	1.2	1.5	1.3	0.8	0.3	1.3	0.5
December	674	325	246	235	1.7	2.5	2.6	1.5	0.3	1.1	1.1	1.6
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	37	53	46	35	12.1	9.8	6.8	4.4	1.8	1.9	0.4	1.4
February	44	64	46	35	7.3	7.1	3.5	2.1	2.9	2.7	0.3	1.5
March	57	64	70	50	9.5	15.5	10.1	8.0	1.3	1.7	0.9	1.9
April	18	20	25	26	2.9	7.3	4.0	3.7	1.7	2.8	1.0	2.5
May	22	30	33	31	4.7	4.6	4.6	3.8	2.1	2.5	0.3	1.7
June	24	32	21	25	3.9	3.9	3.6	3.3	1.7	2.1	1.8	1.2
July	107	117	43	19	4.8	8.8	6.0	4.0	6.8	4.8	1.5	1.4
August	60	80	58	16	3.8	6.4	4.8	2.4	7.7	4.5	0.5	1.0
September	66	77	65	22	4.8	5.0	5.1	2.2	3.5	4.3	0.7	1.3
October	25	41	42	22	3.7	3.7	9.3	2.3	2.2	2.2	0.3	1.0
November	118	132	90	28	2.1	1.1	3.4	1.8	1.0	1.3	0.1	1.4
December	69	233	62	51	2.1	2.9	4.7	2.8	4.2	6.9	0.3	1.8
2011 - Max.	1424	1090	619	463	68.2	78.4	83.4	67.6	60.4	35.1	55.4	34.3
2011 - Avg.	309	317	306	249	15.6	19.2	12.3	7.5	7.4	8.2	2.6	3.4
2011 - Med.	258	285	297	238	15.2	19.0	11.2	6.4	6.5	7.5	2.3	3.1
2011 - Min.	108	120	150	152	1.7	1.2	1.5	0.3	0.3	0.0	1.1	0.4
2011 - S.D.	184	161	79	56	9.2	11.7	7.0	5.0	5.0	5.0	1.2	1.7

Table 6-6: Monthly Statistics for the Old River continuous water quality monitoring stations

	Water Temperature (°C)				Dissolved Oxygen (mg/L)				pH			
Month	Head	TWA	u/s ORT	d/s ORT	Head	TWA	u/s ORT	d/s ORT	Head	TWA	u/s ORT	d/s ORT
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	10.5	10.9	11.0	10.9	10.47	10.26	10.30	10.34	7.55	7.90	8.09	7.69
February	11.6	12.1	12.3	12.2	11.09	11.66	11.70	11.68	8.29	8.27	8.18	8.14
March	14.1	16.2	16.1	16.1	10.65	11.47	11.29	11.04	8.26	8.38	8.81	8.05
April	16.2	17.6	17.7	17.7	9.30	9.64	10.12	9.58	7.36	7.48	7.65	7.62
May	18.8	19.7	19.7	19.5	9.84	9.75	10.32	9.90	7.55	7.67	7.78	7.75
June	21.4	22.6	23.6	23.6	9.98	9.86	9.49	9.27	7.52	7.55	7.84	7.69
July	23.3	25.1	26.0	25.7	11.60	11.44	8.80	8.35	8.61	8.23	7.85	7.62
August	21.6	23.3	23.6	23.6	12.20	12.60	9.69	9.37	8.82	8.58	8.31	8.13
September	21.9	23.8	22.9	23.0	10.27	9.14	7.32	6.76	8.00	7.65	7.66	7.54
October	18.7	19.8	20.6	20.8	9.89	8.92	9.16	9.20	8.10	7.73	7.59	7.72
November	14.9	15.5	17.1	16.7	10.39	12.07	11.23	11.18	8.12	8.31	8.00	8.07
December	11.2	11.2	11.4	11.3	12.47	14.17	15.66	15.73	8.11	8.42	8.87	8.76
	AVERAGES				AVERAGES				AVERAGES			
January	9.3	9.3	9.3	9.3	9.78	9.78	9.42	9.68	7.16	7.49	7.55	7.41
February	10.3	10.4	10.4	10.4	10.53	10.49	10.34	10.43	7.87	7.58	7.69	7.60
March	12.3	12.5	12.7	12.7	10.12	9.93	9.68	9.66	8.18	7.58	7.91	7.57
April	15.5	15.6	15.7	15.6	8.59	8.50	8.42	8.40	7.26	7.31	7.34	7.45
May	16.3	16.8	16.8	16.8	9.32	8.56	8.57	8.60	7.37	7.27	7.34	7.32
June	17.9	18.9	19.6	19.6	9.32	8.50	7.36	7.57	7.33	7.16	7.35	7.43
July	20.7	21.7	22.4	22.5	8.88	8.17	6.58	6.98	7.43	7.30	7.21	7.21
August	19.4	20.7	21.5	21.6	9.71	8.88	6.85	7.01	7.68	7.47	7.31	7.41
September	19.6	20.8	21.3	21.4	9.05	7.38	4.71	5.37	7.48	7.29	7.18	7.34
October	16.3	17.0	17.8	17.8	9.23	8.03	6.82	7.23	7.69	7.43	7.32	7.41
November	12.6	12.6	12.9	12.9	9.75	9.35	9.32	9.54	7.69	7.82	7.62	7.75
December	8.6	8.2	8.4	8.4	11.13	11.26	11.45	11.53	7.86	7.97	7.97	7.92
	MEDIANS				MEDIANS				MEDIANS			
January	9.3	9.5	9.5	9.4	9.77	9.79	9.38	9.66	7.14	7.53	7.51	7.46
February	10.3	10.3	10.3	10.4	10.54	10.46	10.27	10.34	8.14	7.56	7.68	7.62
March	12.5	12.5	12.8	12.8	10.14	10.09	9.83	9.82	8.19	7.59	8.22	7.59
April	15.6	15.6	15.8	15.7	8.58	8.57	8.48	8.55	7.25	7.30	7.34	7.47
May	16.3	16.7	16.8	16.8	9.36	8.61	8.56	8.58	7.39	7.24	7.35	7.31
June	18.0	19.3	20.3	20.3	9.45	8.54	7.38	7.64	7.34	7.16	7.35	7.44
July	20.7	21.5	22.4	22.5	8.71	8.03	6.72	7.15	7.48	7.27	7.22	7.25
August	19.4	20.6	21.5	21.6	9.66	8.83	6.91	7.14	8.08	7.52	7.28	7.42
September	19.5	20.9	21.5	21.6	8.99	7.33	4.73	5.32	7.58	7.33	7.20	7.38
October	16.5	17.0	17.8	17.8	9.20	8.19	7.16	7.81	7.66	7.42	7.32	7.37
November	12.6	12.5	12.8	12.7	9.72	9.20	9.34	9.60	7.62	7.90	7.65	7.73
December	8.6	8.2	8.3	8.4	11.00	11.05	11.04	10.99	7.86	7.97	8.06	8.01
	MINIMUMS				MINIMUMS				MINIMUMS			
January	7.5	7.2	6.9	7.4	9.23	8.89	8.27	8.85	7.01	7.06	7.33	7.09
February	9.3	9.1	9.0	9.4	10.10	9.57	9.35	9.59	7.49	7.34	7.41	6.96
March	9.9	9.6	9.9	10.0	9.45	6.97	6.79	6.65	8.04	7.29	7.32	7.27
April	14.6	13.6	13.4	13.5	8.01	6.76	6.33	5.46	7.13	7.17	7.11	7.32
May	13.9	14.4	14.5	14.5	8.74	5.65	7.28	7.10	7.19	6.93	7.10	6.97
June	14.5	14.8	15.2	15.3	8.19	0.77	5.17	5.61	7.13	6.88	7.07	7.14
July	18.4	19.0	19.6	19.7	7.84	6.49	3.35	5.20	7.07	7.10	6.93	6.86
August	17.7	18.7	19.8	19.9	8.55	7.21	4.38	4.86	6.85	7.06	7.08	7.11
September	17.8	19.0	19.8	19.9	7.08	6.14	2.17	4.15	7.02	7.06	6.90	7.11
October	13.8	14.0	15.0	14.9	7.99	6.34	4.08	4.65	7.21	7.26	7.05	7.11
November	11.2	11.2	11.1	11.2	8.88	7.35	6.97	8.02	7.32	7.39	7.23	7.48
December	6.9	6.1	5.8	6.1	10.18	8.66	8.42	9.79	7.62	7.61	7.46	7.57
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	0.8	0.9	0.9	0.9	0.31	0.23	0.34	0.26	0.14	0.15	0.19	0.13
February	0.5	0.6	0.6	0.6	0.21	0.33	0.39	0.37	0.29	0.15	0.13	0.18
March	1.0	1.3	1.3	1.3	0.29	0.84	0.76	0.72	0.05	0.18	0.38	0.18
April	0.3	0.9	0.9	1.0	0.34	0.70	0.77	0.80	0.05	0.08	0.09	0.07
May	1.0	1.0	0.9	0.9	0.27	0.46	0.42	0.38	0.06	0.14	0.11	0.12
June	1.9	2.0	2.1	2.1	0.44	0.63	0.79	0.73	0.07	0.11	0.15	0.07
July	1.0	1.3	1.4	1.4	0.63	0.77	0.90	0.68	0.29	0.21	0.19	0.14
August	0.7	1.0	0.7	0.7	0.61	0.97	0.87	0.85	0.45	0.27	0.21	0.16
September	0.8	0.8	0.6	0.6	0.41	0.52	0.89	0.52	0.21	0.14	0.15	0.10
October	1.1	1.3	1.3	1.3	0.30	0.58	1.17	1.12	0.20	0.09	0.10	0.16
November	0.7	0.8	1.0	1.1	0.22	0.57	0.52	0.48	0.21	0.19	0.16	0.12
December	0.8	1.0	1.0	1.0	0.44	1.13	1.32	1.37	0.09	0.12	0.32	0.30
2011 - Max.	23.3	25.1	26.0	25.7	12.47	14.17	15.66	15.73	8.82	8.58	8.87	8.76
2011 - Avg.	15.0	15.4	15.7	15.8	9.66	9.06	8.29	8.49	7.51	7.42	7.42	7.45
2011 - Med.	15.6	15.9	16.2	16.2	9.60	8.90	8.51	8.57	7.60	7.46	7.44	7.46
2011 - Min.	6.9	6.1	5.8	6.1	7.08	0.77	2.17	4.15	6.85	6.88	6.90	6.86
2011 - S.D.	4.3	4.7	4.9	5.0	0.78	1.28	1.98	1.86	0.36	0.28	0.35	0.26

Table 6-6 (continued): Monthly Statistics for the Old River continuous water quality monitoring stations

	Specific Conductance (µS/cm)				Turbidity (NTU)				Chlorophyll (µg/L)			
Month	Head	TWA	u/s ORT	d/s ORT	Head	TWA	u/s ORT	d/s ORT	Head	TWA	u/s ORT	d/s ORT
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	315	901	624	650	67.2	51.5	71.2	57.2	6.4	32.6	15.8	11.0
February	318	722	578	579	46.0	54.8	64.2	26.6	14.5	45.8	24.1	17.1
March	354	939	714	722	39.4	68.3	59.3	48.1	8.0	72.8	32.7	138.3
April	148	229	265	267	22.1	73.1	83.4	52.9	6.5	23.7	13.4	9.1
May	214	518	380	386	41.1	36.3	70.3	62.6	21.0	78.4	25.7	125.8
June	197	680	435	423	38.1	51.2	67.2	103.7	28.0	50.8	20.6	71.9
July	419	605	543	545	50.7	61.8	68.0	60.1	66.6	67.0	17.6	19.7
August	409	587	541	540	51.5	38.0	62.7	38.5	57.4	82.1	23.2	46.7
September	458	594	617	622	40.0	53.1	54.6	36.8	41.7	21.3	15.7	5.7
October	290	1152	704	705	41.9	37.9	62.9	154.7	35.1	19.6	6.6	12.1
November	695	1063	931	957	36.7	28.1	44.4	33.0	14.4	111.2	38.3	49.6
December	847	1271	1143	1173	38.1	26.7	33.0	39.7	31.8	69.8	61.6	148.6
	AVERAGES				AVERAGES				AVERAGES			
January	225	294	316	314	32.5	25.3	17.5	19.0	3.7	6.0	3.9	2.7
February	273	346	373	368	20.7	16.4	10.7	10.8	4.7	9.4	5.4	2.4
March	296	340	373	371	17.4	21.2	15.0	16.5	5.1	12.0	5.8	2.8
April	141	178	190	194	18.4	21.5	14.7	18.0	4.5	9.5	6.2	3.3
May	167	227	237	237	20.7	22.5	16.3	19.2	11.0	14.5	5.2	3.6
June	160	240	280	278	21.4	24.0	18.4	22.1	13.4	18.4	4.6	5.2
July	216	265	286	284	24.5	26.6	20.1	23.1	28.5	28.7	6.5	6.8
August	246	308	354	354	15.7	22.7	18.1	19.3	23.0	23.0	6.4	7.3
September	304	390	446	443	14.6	18.0	11.8	11.3	18.5	8.4	3.4	2.2
October	254	377	387	382	14.2	16.8	11.1	15.6	6.6	5.9	2.9	2.2
November	556	687	542	519	10.8	15.0	5.8	7.1	3.5	19.1	4.5	3.6
December	787	919	759	719	6.2	11.3	5.3	5.6	6.9	20.7	11.1	15.0
	MEDIANS				MEDIANS				MEDIANS			
January	225	270	304	301	30.8	26.3	16.5	17.8	3.6	5.2	3.5	2.4
February	271	319	361	354	17.8	13.3	9.4	9.8	4.4	8.3	4.0	1.6
March	293	322	363	355	16.7	16.9	11.8	13.4	5.0	10.9	5.1	2.2
April	140	175	185	187	18.4	18.6	13.3	17.0	4.5	7.8	5.8	2.5
May	163	218	223	225	20.5	22.3	14.5	17.8	11.3	13.4	4.6	2.7
June	165	227	279	279	21.1	23.6	17.2	20.3	11.5	17.5	4.3	4.8
July	180	230	253	254	25.5	26.7	18.9	22.7	25.1	25.2	6.2	6.3
August	248	300	345	346	14.6	22.7	17.4	18.6	20.3	19.5	5.7	5.6
September	306	392	466	465	13.7	17.9	10.8	11.1	17.2	8.1	3.3	2.2
October	260	345	421	413	13.5	15.7	10.3	12.0	5.2	5.5	2.9	2.1
November	589	697	582	556	10.3	14.7	4.8	6.0	3.4	15.0	2.9	1.6
December	793	906	880	795	5.9	11.0	4.7	5.0	5.4	18.5	4.9	2.7
	MINIMUMS				MINIMUMS				MINIMUMS			
January	156	161	181	180	13.6	7.5	5.9	3.5	2.0	1.8	1.8	0.5
February	211	227	230	230	11.1	6.6	3.9	3.4	2.5	1.7	1.2	0.1
March	252	202	211	199	12.0	5.6	4.2	4.7	3.5	4.1	1.8	0.4
April	136	152	159	159	15.0	13.4	7.4	7.6	2.6	1.7	2.0	0.6
May	138	157	155	151	16.4	9.2	7.8	7.5	3.6	2.1	1.7	0.6
June	119	138	170	159	14.9	15.0	8.6	9.8	5.2	9.6	1.8	1.6
July	108	125	145	145	9.7	17.6	6.7	9.4	11.9	13.1	2.5	1.5
August	148	178	239	211	8.7	12.4	7.0	7.9	8.4	4.4	1.7	0.7
September	170	237	249	248	7.9	9.4	3.9	5.0	6.7	2.8	1.3	0.5
October	194	211	183	182	7.2	6.9	2.3	2.5	2.2	1.7	1.1	0.4
November	263	302	180	177	4.7	5.5	1.7	1.8	0.8	1.5	1.2	0.3
December	681	740	232	232	3.2	5.0	1.7	1.8	1.8	3.3	1.2	0.5
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	36	95	62	64	11.0	9.2	7.9	8.8	0.8	3.1	1.5	1.2
February	22	90	72	75	6.8	7.1	4.9	4.4	1.2	6.4	3.9	2.5
March	27	102	78	79	2.7	13.5	8.7	9.0	0.6	6.1	2.8	4.7
April	3	15	20	22	1.4	9.0	6.0	7.4	0.6	4.7	2.5	2.0
May	17	48	48	50	1.8	5.0	6.8	7.1	3.7	8.9	2.1	4.5
June	21	67	41	46	2.5	4.0	5.8	8.5	5.6	4.9	1.5	2.1
July	107	114	100	101	5.5	3.2	6.9	7.2	11.2	10.9	1.9	2.6
August	58	62	60	61	4.6	3.5	5.2	6.3	10.2	15.0	2.9	6.1
September	63	69	85	85	3.9	2.9	4.5	2.6	7.0	3.4	1.0	0.5
October	25	131	111	114	3.6	4.8	5.5	12.3	4.4	1.9	0.6	0.9
November	113	138	241	248	3.2	2.7	3.6	4.0	1.0	15.3	4.9	6.8
December	28	72	276	286	2.2	2.9	3.1	2.6	4.8	12.4	12.9	27.8
2011 - Max.	847	1271	1143	1173	67.2	73.1	83.4	154.7	66.6	111.2	61.6	148.6
2011 - Avg.	314	381	379	378	17.7	20.2	13.8	15.6	11.5	14.7	5.6	4.8
2011 - Med.	260	308	328	328	17.1	18.9	12.7	13.9	6.8	11.4	4.3	2.6
2011 - Min.	108	125	145	145	3.2	5.0	1.7	1.8	0.8	1.5	1.1	0.1
2011 - S.D.	193	223	193	187	8.1	7.9	7.6	9.1	10.1	11.5	5.0	9.7



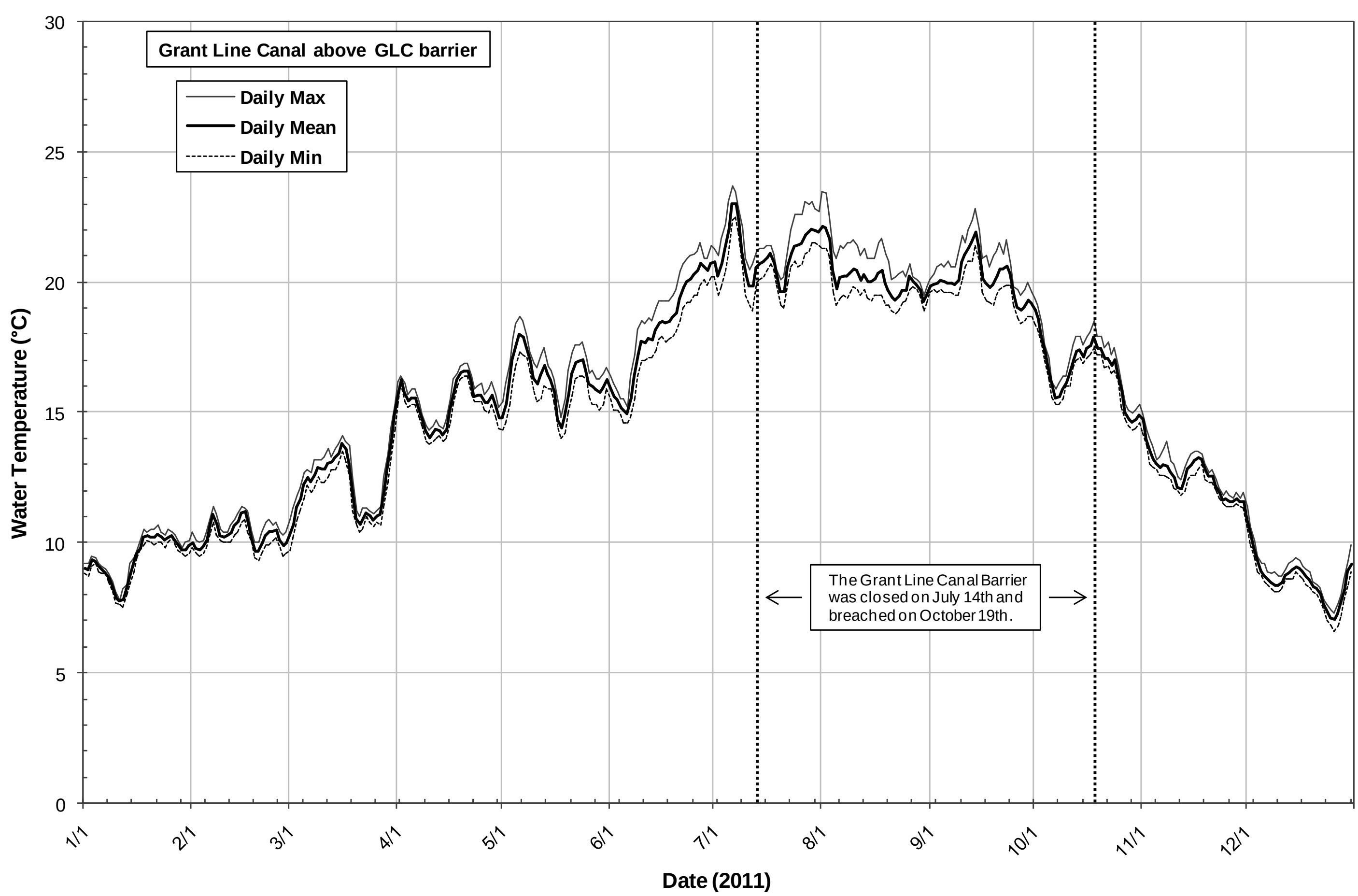
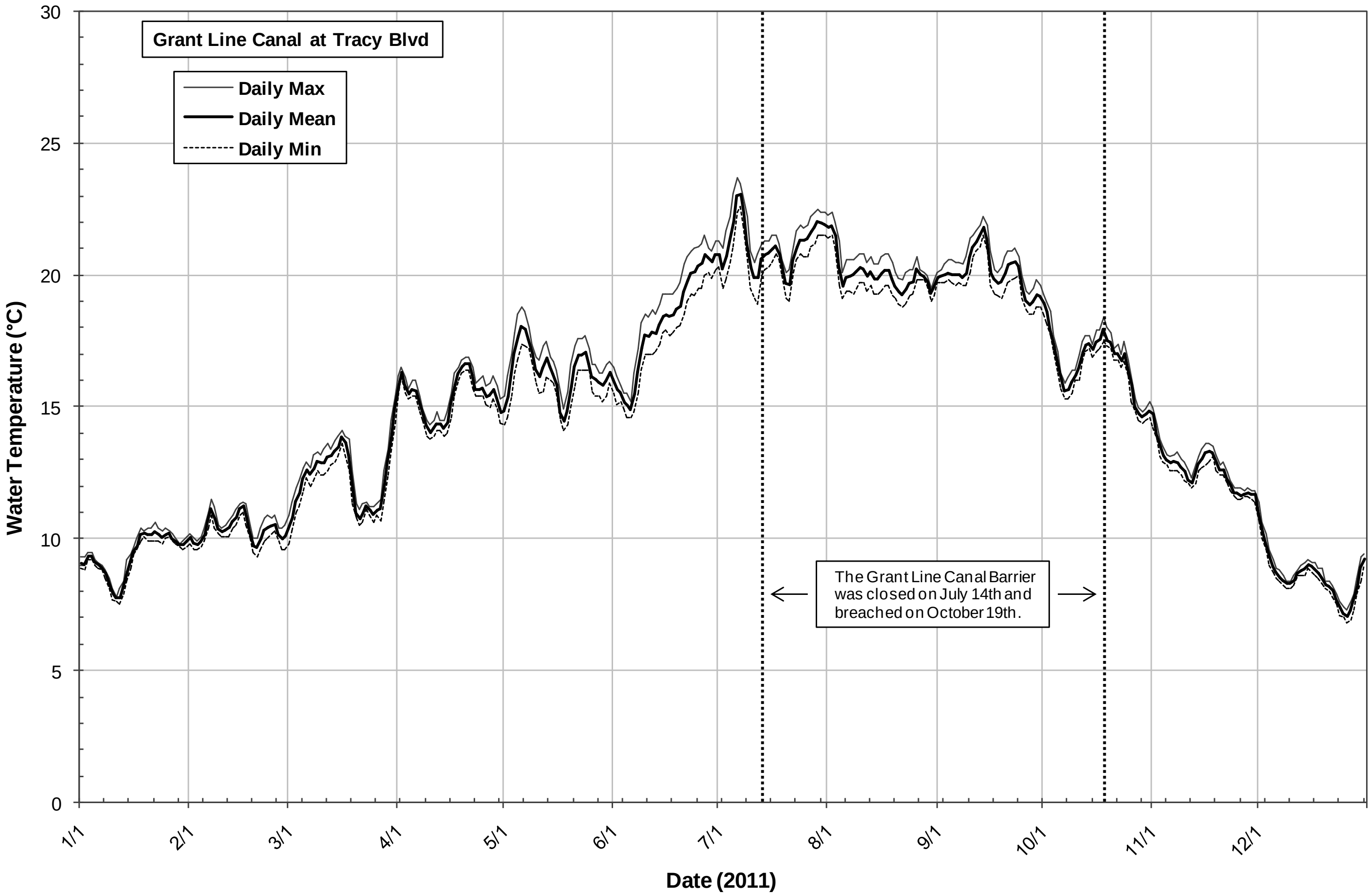


Figure 6-2: Daily Temperature time-series graphs for the Grant Line and Victoria Canal stations



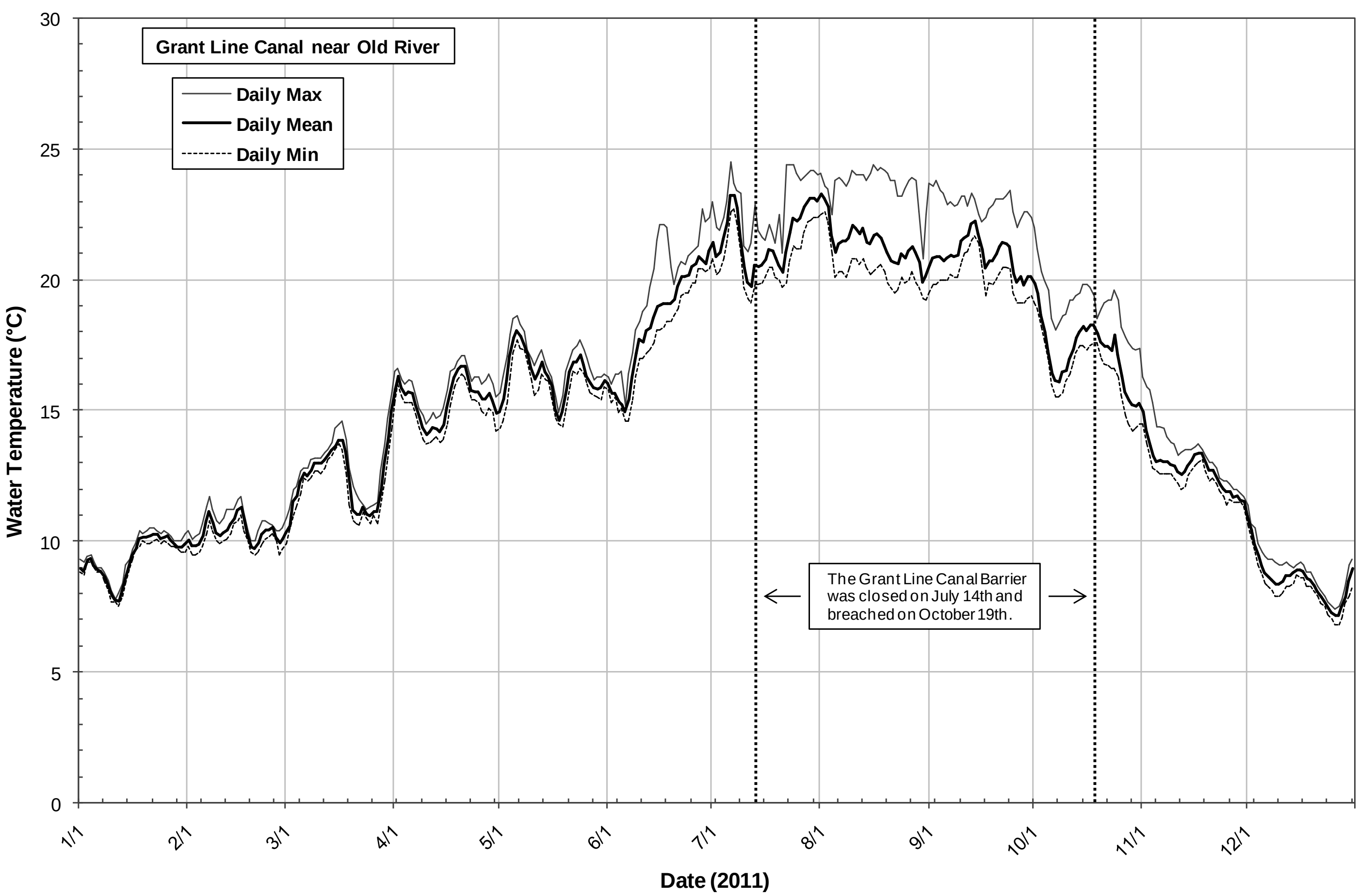


Figure 6-2: Daily Temperature time-series graphs for the Grant Line and Victoria Canal stations

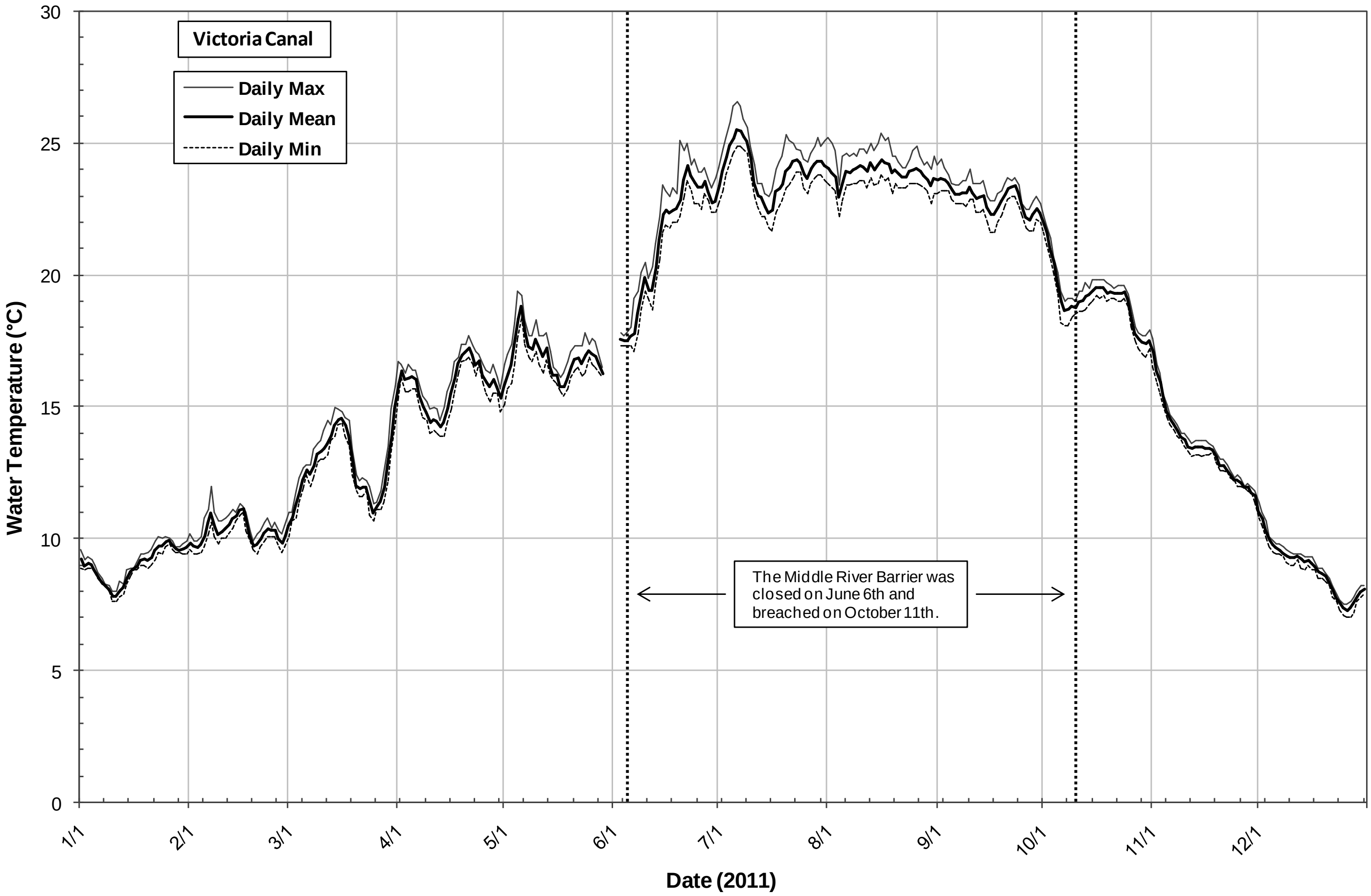
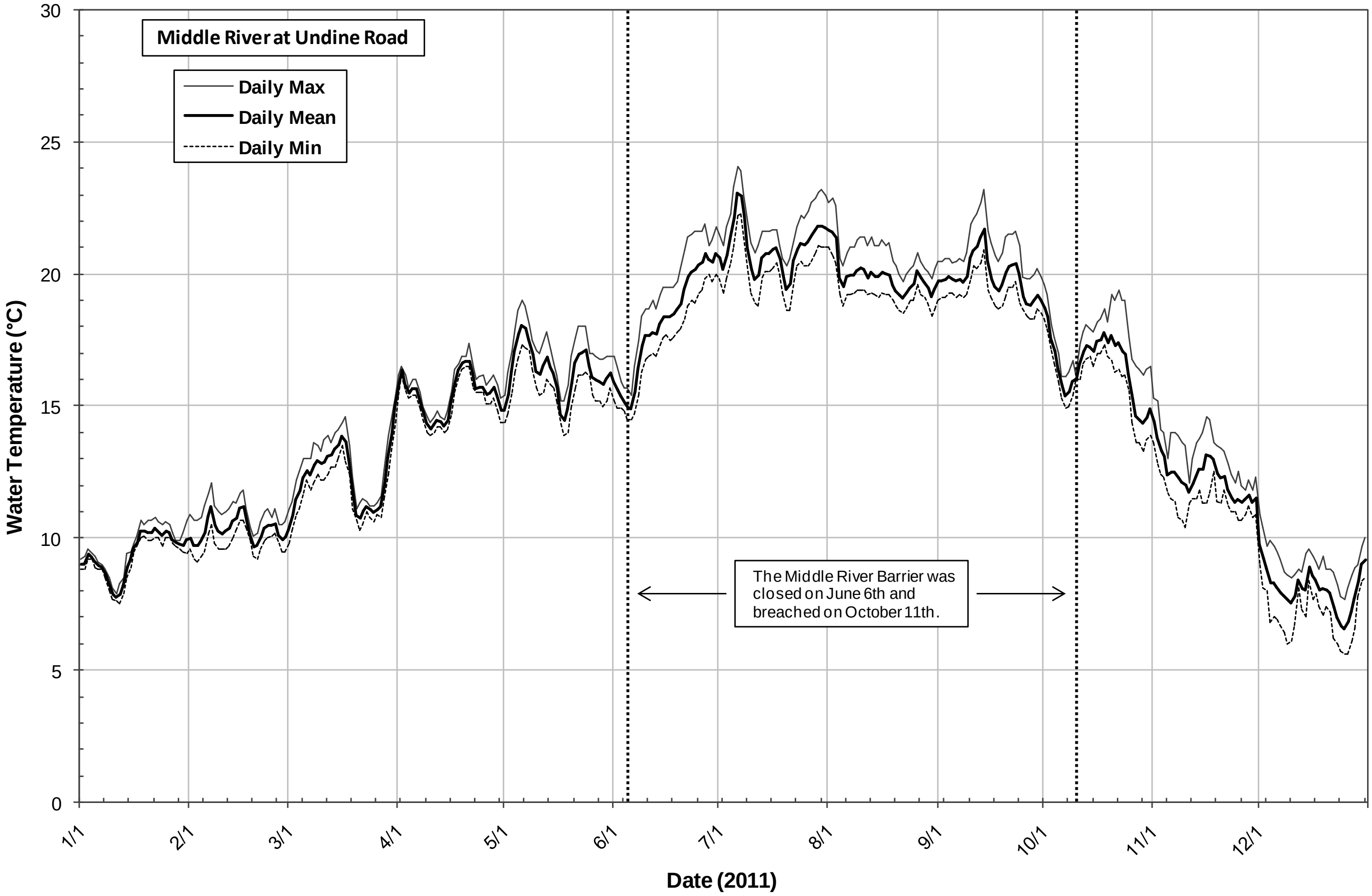


Figure 6-2: Daily Temperature time-series graphs for the Grant Line and Victoria Canal stations



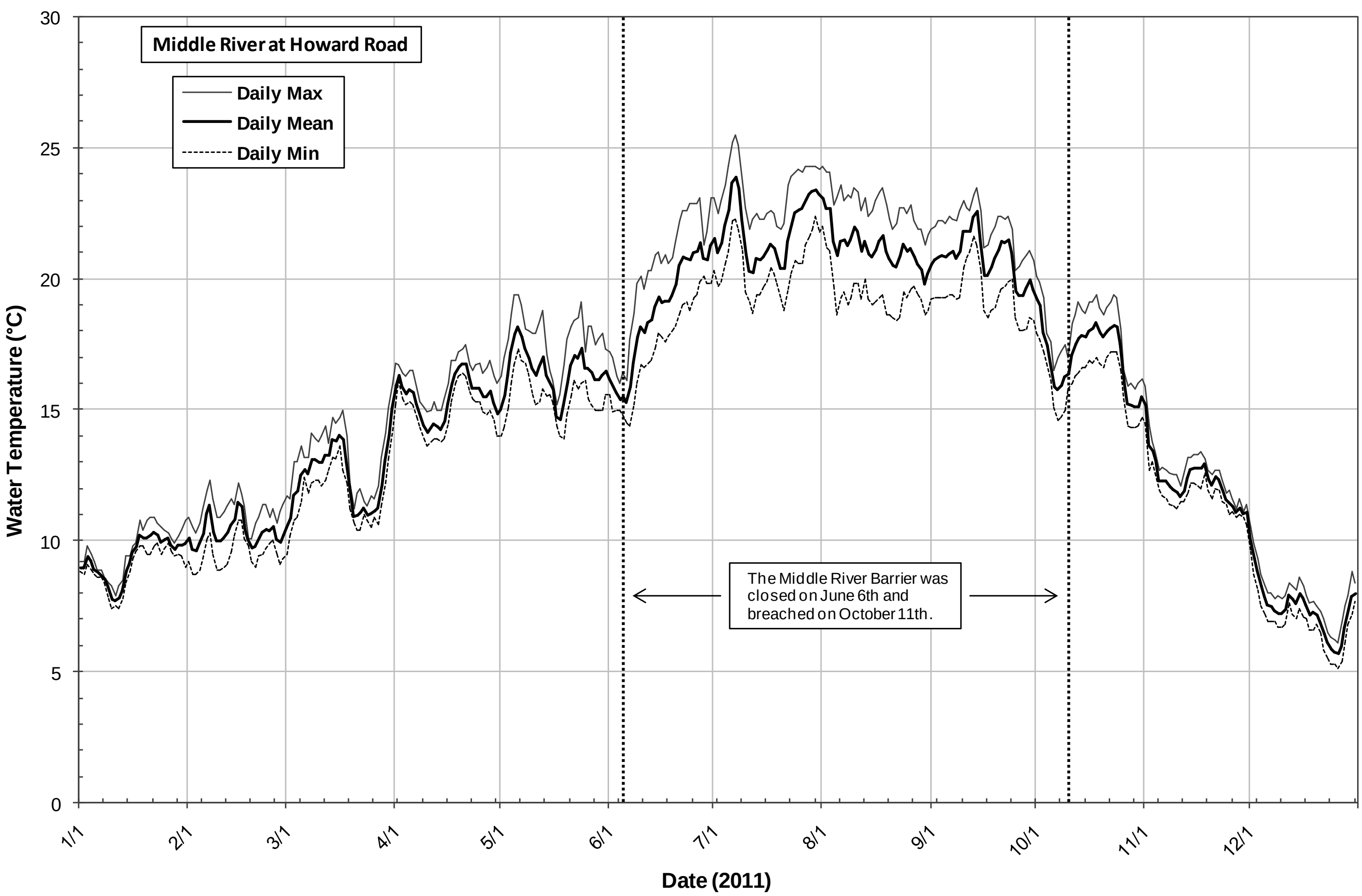
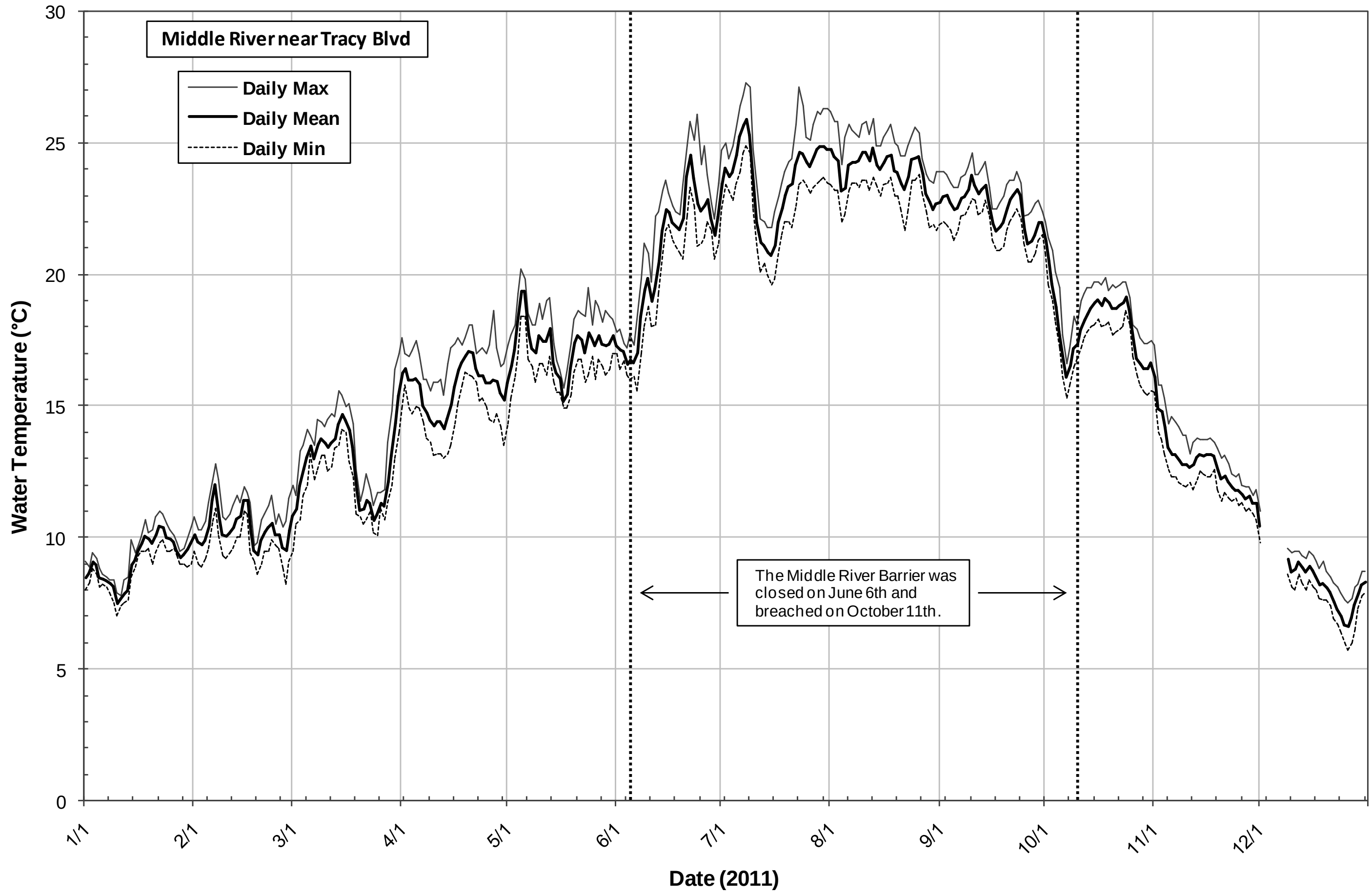


Figure 6-3: Daily Temperature time-series graphs for the Middle River stations



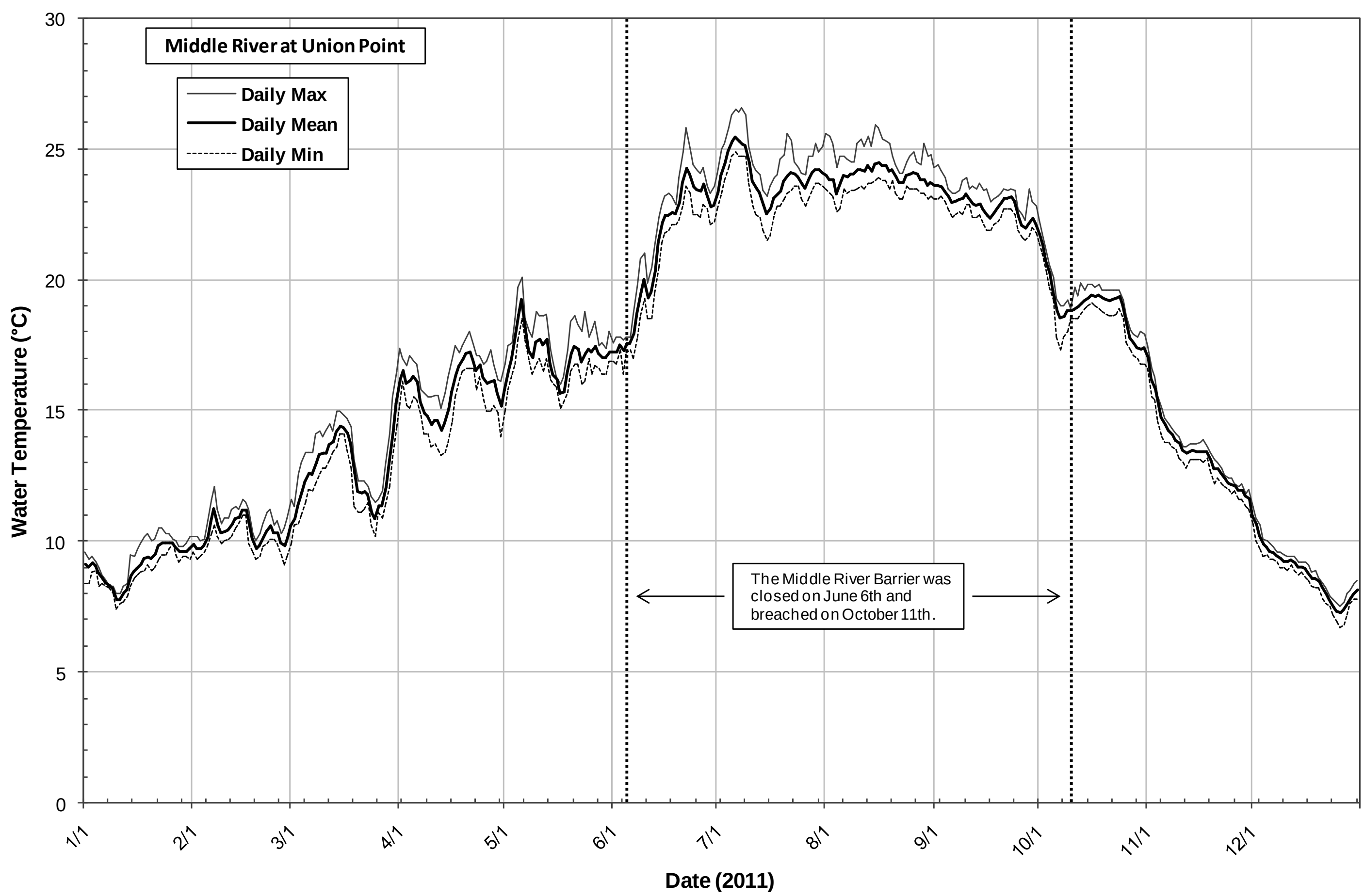
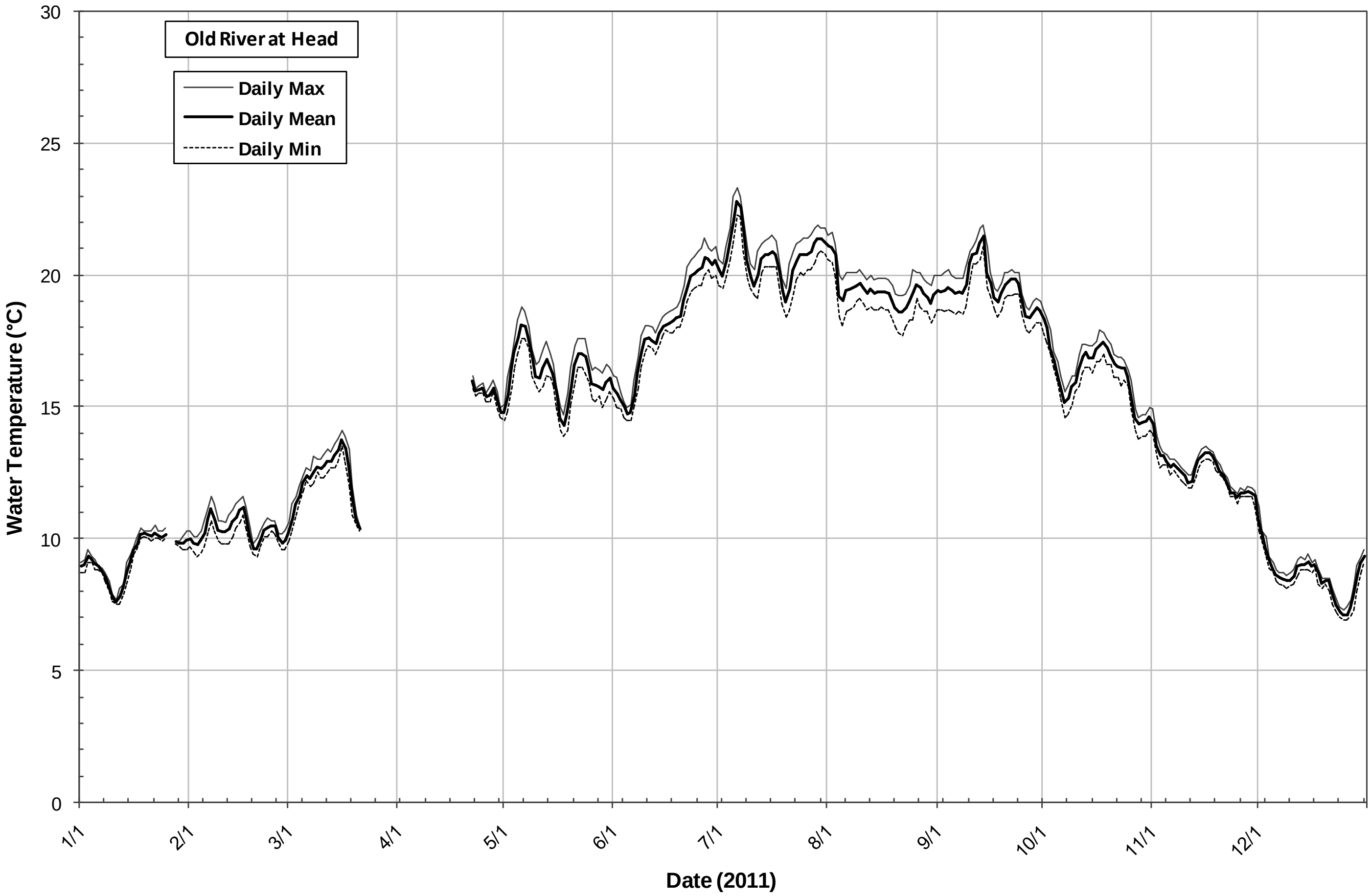


Figure 6-3: Daily Temperature time-series graphs for the Middle River stations



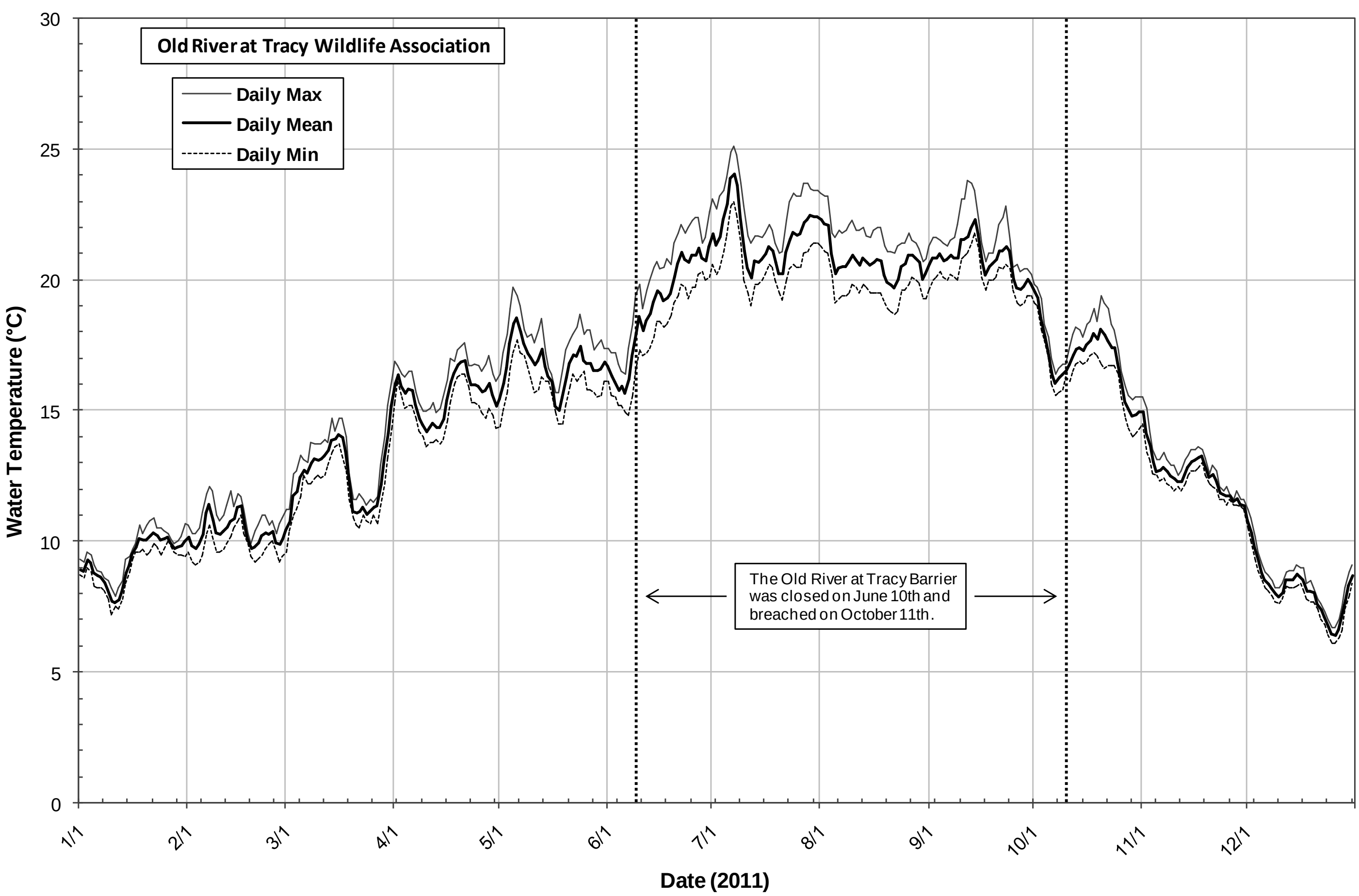
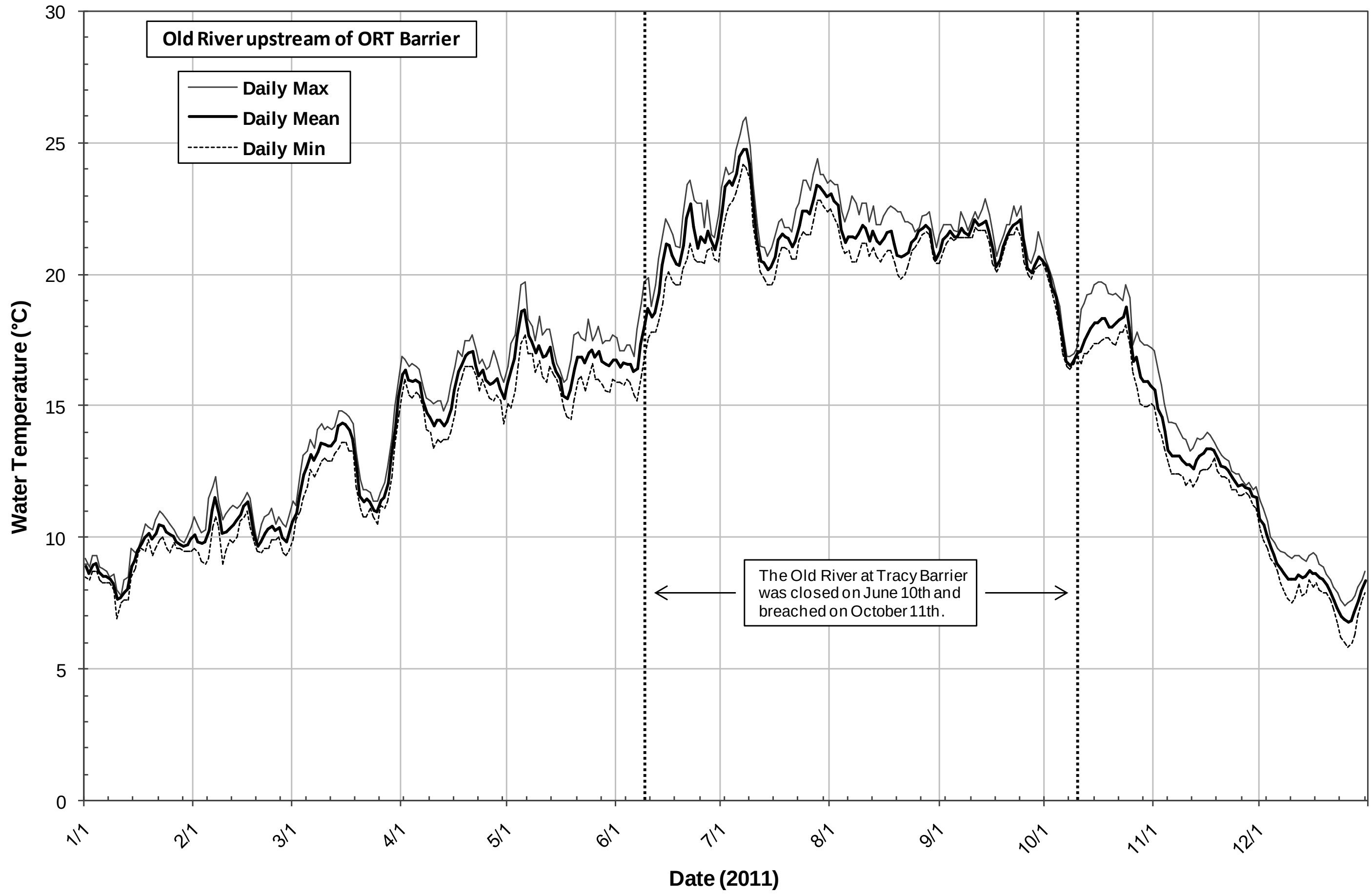


Figure 6-4: Daily Temperature time-series graphs for the Old River stations



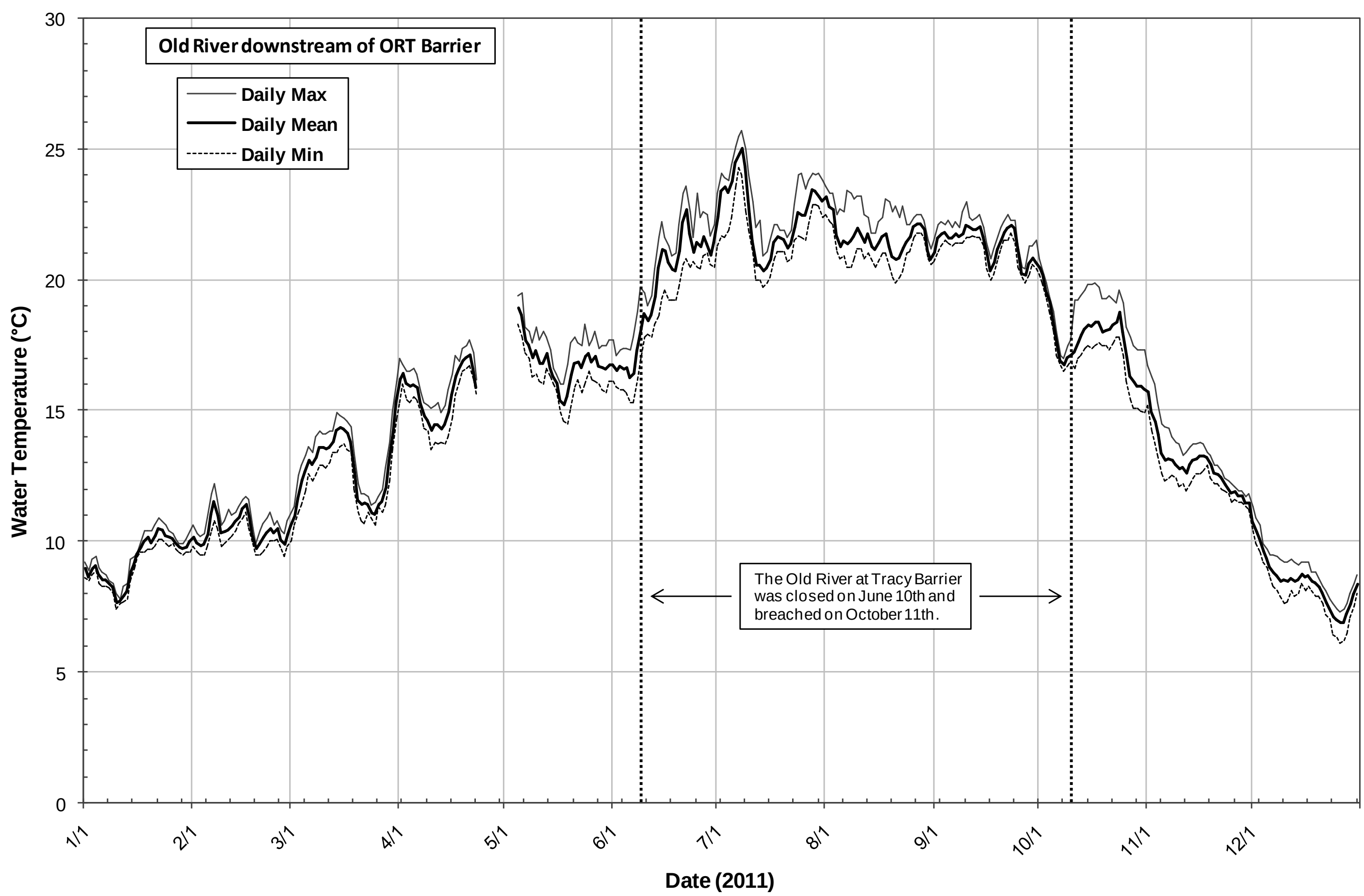


Figure 6-4: Daily Temperature time-series graphs for the Old River stations

Dissolved Oxygen

One of the most important measures of water quality is the amount of dissolved oxygen (Masters, 1997). Sources of dissolved oxygen in surface waters are primarily atmospheric reaeration and photosynthetic activity of aquatic plants (Lewis, 2005). Dissolved oxygen saturation is inversely related to water temperature (i.e. as water temperature increases, dissolved oxygen saturation decreases). Super saturated dissolved oxygen conditions can occur as a result of high rates of photosynthetic production of oxygen by phytoplankton and/or aquatic plants. The depletion of dissolved oxygen can occur by inorganic oxidation reactions or by biological or chemical processes that consume dissolved, suspended, or precipitated organic matter (Hem, 1989).

During the 2011 monitoring period, a maximum dissolved oxygen concentration of 15.96 mg/L was recorded on December 26th at Middle River at Howard Road, and a minimum of 0.77 mg/L was recorded on June 15th at Old River at Tracy Wildlife Association (Tables 6-3 to 6-6). Figures 6-5, 6-6, and 6-7 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively.

At most of the stations during the spring, there were two periods of time with obvious decreases in dissolved oxygen concentrations: one from the end of March to the beginning of April and the other from mid-April to end of April. Monthly average concentrations during the spring season (March – May) ranged from 7.12 mg/L in April at Middle River at Undine Road to 10.12 mg/L in March at Old River at Head. None of the South Delta stations appeared to have an increase in dissolved oxygen concentrations commonly seen during the spring as a result of an increase in photosynthetic activity in the water. In addition, there were no obvious increases in chlorophyll *a* concentrations during the spring at any of these stations (Figures 6-29, 6-30, and 6-31).

Typically, dissolved oxygen concentrations are significantly lower overall during the summer and early fall months, most likely due to the warmer water temperatures; however, during 2011 the dissolved oxygen concentrations during the warmer months at most of the stations either were slightly lower, stayed at approximately the same values as during the spring, or increased slightly. This unusual trend may have been partially due to the extremely wet winter and spring in early 2011. The one station with an exception to this trend was Middle River near Tracy Blvd. Dissolved oxygen concentrations during the summer at this station were very low with a period of 62 consecutive days where the daily average concentrations did not exceed 5 mg/L (from August 6th to October 6th). Monthly average concentrations during the summer and early fall (June - September) at the South Delta stations ranged from 3.74 mg/L in September at Middle River near Tracy Blvd to 9.81 mg/L in August at Grant Line Canal at Tracy Blvd (Tables 6-3 to 6-6).

At the beginning of November 2011, the dissolved oxygen concentrations at all of the stations started to increase, which was most likely due to decreasing water temperatures. During November and December 2011, monthly average concentrations ranged from 8.80 mg/L in November at Middle River near Tracy Blvd to 11.68 mg/L in December at Middle River at Undine Road. At some of the South Delta stations, the increase in dissolved oxygen concentrations at the end of 2011 could have also been a result of an increase in photosynthesis in the water indicated by increasing chlorophyll *a* concentrations (Figures 6-29, 6-30, and 6-31).

Water Quality Standard Exceedences:

As discussed in the Methods and Results section, the established dissolved oxygen criteria is 5 mg/L; therefore, staff considered any dissolved oxygen sample of reliable data quality less than 5.0 mg/L as exceeding the standard. Figures 6-8, 6-9, and 6-10 illustrate the number of dissolved oxygen readings with concentrations less than 5.0 mg/L for each season and the overall total for the 2011 monitoring period for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively. In addition, the figures show the percent of sonde samples exceeding the dissolved oxygen standard relative to the total number of samples collected. Figures 6-11, 6-12, and 6-13 provide the exceedence information in a map format allowing for the observation of geographical relationships.

The station with the most exceedences during 2011 was Middle River near Tracy Blvd with a total of 5,680 (16.7% of the total number of samples). Most of the standard exceedences at the Tracy Blvd station occurred in the summer (2,627; 29.7% of all samples collected in the summer) and the fall (3,053; 36.3% of all samples collected in the fall). The only other station that had a large number of exceedences for the year was Old River upstream of the ORT barrier (2,128; 6.1% of the total). Five stations had no dissolved oxygen readings with values less than 5 mg/L during 2011: Doughty Cut above Grant Line Canal, Grant Line Canal above the GLC barrier, Grant Line Canal at Tracy Blvd, Grant Line Canal near Old River, and Old River at Head. For the stations that had dissolved oxygen exceedences during 2011, most of the exceedences occurred during the summer and fall seasons.

For the stations located along Old River, the stations closest to the ORT barrier had higher total numbers of exceedences during 2011 than the stations upstream or downstream (Figures 6-10 and 6-13). The Old River upstream and downstream of the ORT barrier stations had 2,128 and 753 total exceedences, respectively, compared to Old River at Tracy Wildlife Association with three and Old River at Head with zero. The stations located along Middle River followed the same trend, but it was less obvious. The Middle River near Tracy Blvd and Middle River at Union Point stations had 5,680 and 57 total exceedences, respectively, compared to Middle River at Undine Road with one and Middle River at Howard Road with three (Figures 6-9 and 6-12). The stations located along Grant Line Canal had no relationship between the number of dissolved oxygen exceedences and the proximity to the temporary barriers (Figures 6-8 and 6-11).

Station Comparisons by Season:

Grant Line Canal

The Grant Line Canal near Old River station had significantly lower dissolved oxygen concentrations than the three other stations along Grant Line Canal during the summer and fall (summer: $p<0.00001$, fall: $p< 0.0006$; Tables 6-8 and 6-9). In the fall, Doughty Cut above Grant Line Canal had significantly higher dissolved oxygen concentrations than the three other stations ($p<0.04$; Table 6-9).

Table 6-7: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Grant Line Canal stations - **Spring**

Station	**Seasonal Median DO Conc (mg/L)**	**Pair-wise Comparison p-value [a]**			
		GLC near OR	**GLC at Tracy Blvd**	**GLC above barrier**	**Doughty Cut abv GLC**
GLC near OR	9.04	--	NS	0.03530	NS
GLC at Tracy Blvd	9.20	NS	--	NS	NS
GLC above barrier	9.32	0.03530	NS	--	NS
Doughty Cut abv GLC	9.39	NS	NS	NS	--

[a] "NS" stands for "no significant difference between the two stations" in all of these tables.

Table 6-8: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Grant Line Canal stations - **Summer**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		GLC near OR	GLC above barrier	GLC at Tracy Blvd	Doughty Cut abv GLC
GLC near OR	8.21	--	0.00000	0.00000	0.00000
GLC above barrier	9.18	0.00000	--	NS	NS
GLC at Tracy Blvd	9.23	0.00000	NS	--	NS
Doughty Cut abv GLC	9.27	0.00000	NS	NS	--

Table 6-9: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Grant Line Canal stations - **Fall**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		GLC near OR	GLC above barrier	GLC at Tracy Blvd	Doughty Cut abv GLC
GLC near OR	8.23	--	0.00059	0.00000	0.00000
GLC above barrier	8.95	0.00059	--	NS	0.00132
GLC at Tracy Blvd	9.08	0.00000	NS	--	0.03629
Doughty Cut abv GLC	9.31	0.00000	0.00132	0.03629	--

Middle River

Middle River at Tracy Blvd had significantly lower dissolved oxygen concentrations than the three other Middle River stations during the summer and fall (summer: $p<0.004$, fall: $p<0.00002$; Tables 6-11 and 6-12). The seasonal median dissolved oxygen concentrations at the Tracy Blvd station were 5.93 mg/L in the summer and 6.15 mg/L in the fall. In the summer, every pair-wise comparison among the four Middle River stations was statistically different ($p<0.004$; Table 6-11). In the fall, Middle River at Union Point had significantly lower dissolved oxygen concentrations than both the Middle River at Howard Road and Middle River at Undine Road stations ($p<0.00001$, Table 6-12).

Table 6-10: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Middle River stations - **Spring**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value [a]			
		Middle River nr Tracy Blvd	Middle River at Undine Rd	Middle River at Union Point	Middle River at Howard Rd
Middle River nr Tracy Blvd	8.79	--	NS	NS	NS
Middle River at Undine Rd	8.86	NS	--	NS	0.01595
Middle River at Union Point	8.96	NS	NS	--	NS
Middle River at Howard Rd	9.18	NS	0.01595	NS	--

[a] "NS" stands for "no significant difference between the two stations" in all of these tables.

Table 6-11: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Middle River stations - **Summer**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		Middle River nr Tracy Blvd	Middle River at Union Point	Middle River at Howard Rd	Middle River at Undine Rd
Middle River nr Tracy Blvd	5.93	--	0.00356	0.00000	0.00000
Middle River at Union Point	7.15	0.00356	--	0.00000	0.00000
Middle River at Howard Rd	8.31	0.00000	0.00000	--	0.00000
Middle River at Undine Rd	9.23	0.00000	0.00000	0.00000	--

Table 6-12: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Middle River stations - **Fall**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		Middle River nr Tracy Blvd	Middle River at Union Point	Middle River at Howard Rd	Middle River at Undine Rd
Middle River nr Tracy Blvd	6.15	--	0.00001	0.00000	0.00000
Middle River at Union Point	7.80	0.00001	--	0.00000	0.00000
Middle River at Howard Rd	8.80	0.00000	0.00000	--	NS
Middle River at Undine Rd	8.98	0.00000	0.00000	NS	--

Old River

Old River at Head had significantly higher dissolved oxygen concentrations than the three other Old River stations during every season analyzed (spring: $p<0.0003$, summer: $p<0.00002$, fall: $p<0.00001$; Tables 6-13 to 6-15). The two stations closest to the ORT barrier, Old River upstream and downstream of the barrier, had significantly lower dissolved oxygen concentrations than the two upstream stations during the summer ($p<0.00001$; Table 6-14). In the fall, just the Old River upstream of the ORT barrier station had significantly lower dissolved oxygen concentrations than the two upstream stations ($p<0.006$; Table 6-15). The dissolved oxygen concentrations of the two stations adjacent to the ORT barrier were not significantly different during the spring, summer, and fall ($p>0.05$).

Table 6-13: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Old River stations - **Spring**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value [a]			
		Old River u/s ORT barrier	Old River at TWA	Old River d/s ORT barrier	Old River at Head
Old River u/s ORT barrier	8.74	--	NS	NS	0.00000
Old River at TWA	8.78	NS	--	NS	0.00020
Old River d/s ORT barrier	8.80	NS	NS	--	0.00004
Old River at Head	9.52	0.00000	0.00020	0.00004	--

[a] "NS" stands for "no significant difference between the two stations" in all of these tables.

Table 6-14: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Old River stations - **Summer**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		Old River u/s ORT barrier	Old River d/s ORT barrier	Old River at TWA	Old River at Head
Old River u/s ORT barrier	6.98	--	NS	0.00000	0.00000
Old River d/s ORT barrier	7.28	NS	--	0.00000	0.00000
Old River at TWA	8.52	0.00000	0.00000	--	0.00001
Old River at Head	9.37	0.00000	0.00000	0.00001	--

Table 6-15: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Old River stations - **Fall**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		Old River u/s ORT barrier	Old River d/s ORT barrier	Old River at TWA	Old River at Head
Old River u/s ORT barrier	7.32	--	NS	0.00576	0.00000
Old River d/s ORT barrier	7.83	NS	--	NS	0.00000
Old River at TWA	8.20	0.00576	NS	--	0.00000
Old River at Head	9.31	0.00000	0.00000	0.00000	--

Upstream/Downstream Station Comparisons:

Grant Line Canal Barrier

The upstream station, Grant Line Canal above the GLC barrier, had significantly higher dissolved oxygen concentrations than the downstream station, Grant Line Canal at Tracy Blvd, during the months of March, April, and May 2011 (Table 6-16). Grant Line Canal at Tracy Blvd had significantly higher dissolved oxygen concentrations than Grant Line Canal above the GLC barrier during the months of July, August, September, October, and December 2011.

Table 6-16: Results for the Upstream-Downstream Analysis for the Grant Line Canal barrier

	Monthly Median DO Conc (mg/L) [a]		1-sample Wilcoxon Test Results [b]		
Month	**Upstream Station - GLC above the barrier**	**Downstream Station - GLC at Tracy Blvd**	**p-value**	**Difference between Monthly Medians (mg/L)**	**Station with significantly higher DO values [c]**
January	9.86	9.81	NS	NS	NS
February	10.47	10.43	NS	NS	NS
March	10.15	9.94	<0.001	0.21	GLAB
April	8.60	8.51	<0.001	0.09	GLAB
May	9.32	9.18	<0.001	0.14	GLAB
June	9.23	9.23	NS	NS	NS
July	8.53	8.60	<0.001	0.08	GLTR
August	9.49	9.77	<0.001	0.28	GLTR
September	8.54	8.67	<0.001	0.14	GLTR
October	8.65	8.81	0.002	0.17	GLTR
November	9.45	9.47	NS	NS	NS
December	10.89	11.00	0.015	0.11	GLTR

[a] The monthly medians are actually the medians of the daily medians for the month. For example, in this analysis the monthly median for January is the median of all of the daily medians for the month of January.

[b] "NS" stands for "no significant difference between the two stations".

[c] "GLTR" represents the Grant Line Canal at Tracy Blvd station. "GLAB" represents the Grant Line Canal above the GLC barrier station.

Middle River Barrier

The upstream station, Middle River near Tracy Blvd, had significantly higher dissolved oxygen concentrations than the downstream station, Middle River at Union Point, during the cooler months of 2011 (January, February, and December; Table 6-17). During the warmer months (May and July – November 2011), Middle River at Union Point had significantly higher dissolved oxygen concentrations than Middle River near Tracy Blvd. In August and September the differences between the monthly medians of the two stations were relatively large with a difference of 2.83 mg/L in August and 3.82 mg/L in September.

Table 6-17: Results for the Upstream-Downstream Analysis for the Middle River barrier

	Monthly Median DO Conc (mg/L) [(a)]		Mann-Whitney Test Results [(b)]		
Month	**Upstream Station - MR near Tracy Blvd**	**Downstream Station - MR at Union Point**	**p-value**	**Difference between Monthly Medians (mg/L)**	**Station with significantly higher DO values [(c)]**
January	9.90	9.33	<0.0001	0.57	MRNT
February	10.64	10.30	0.0305	0.33	MRNT
March	10.15	9.88	NS	NS	NS
April	8.65	8.69	NS	NS	NS
May	8.62	8.76	0.0243	0.15	MRUP
June	7.61	7.69	NS	NS	NS
July	5.87	6.86	<0.0001	0.99	MRUP
August	4.27	7.09	<0.0001	2.83	MRUP
September	3.43	7.25	<0.0001	3.82	MRUP
October	6.15	7.80	<0.0001	1.65	MRUP
November	8.77	9.41	0.0003	0.64	MRUP
December	10.59	10.15	<0.0001	0.45	MRNT

(a) The monthly medians are actually the medians of the daily medians for the month. For example, in this analysis the monthly median for January is the median of all of the daily medians for the month of January.

(b) "NS" stands for "no significant difference between the two stations".

(c) "MRNT" represents the Middle River near Tracy Blvd station. "MRUP" represents the Middle River at Union Point station.

Old River at Tracy Barrier

The downstream station, Old River downstream of the ORT barrier, had significantly higher dissolved oxygen concentrations than the upstream station, Old River upstream of the ORT barrier, during the months of January, July, September, and November 2011 (Table 6-18). There were no significant differences in dissolved oxygen concentrations between these two stations during the remaining months.

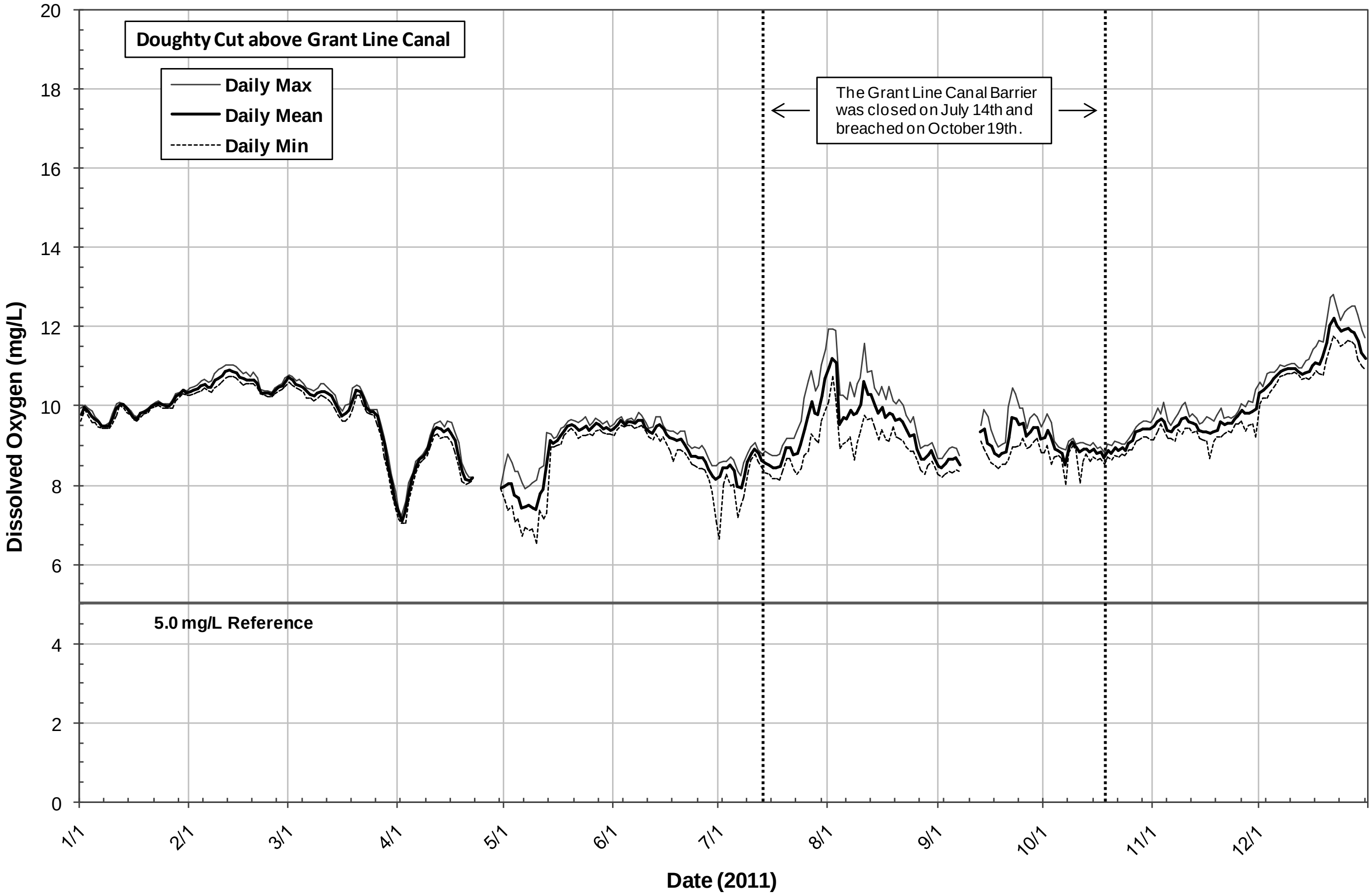
Table 6-18: Results for the Upstream-Downstream Analysis for the Old River at Tracy barrier

	Monthly Median DO Conc (mg/L) [a]		Mann-Whitney Test Results [b]		
Month	Upstream Station - OR u/s ORT barrier	Downstream Station - OR d/s ORT barrier	p-value	Difference between Monthly Medians (mg/L)	Station with significantly higher DO values [c]
January	9.37	9.70	0.0005	0.33	ORDB
February	10.29	10.36	NS	NS	NS
March	9.87	9.87	NS	NS	NS
April	8.54	8.61	NS	NS	NS
May	8.49	8.53	NS	NS	NS
June	7.28	7.56	NS	NS	NS
July	6.81	7.29	0.0187	0.49	ORDB
August	6.91	7.21	NS	NS	NS
September	4.78	5.20	0.0009	0.42	ORDB
October	7.32	7.83	NS	NS	NS
November	9.39	9.66	0.0045	0.27	ORDB
December	11.70	11.33	NS	NS	NS

[a] The monthly medians are actually the medians of the daily medians for the month. For example, in this analysis the monthly median for January is the median of all of the daily medians for the month of January.

[b] "NS" stands for "no significant difference between the two stations".

[c] "ORDB" represents the Old River downstream of the ORT barrier station.



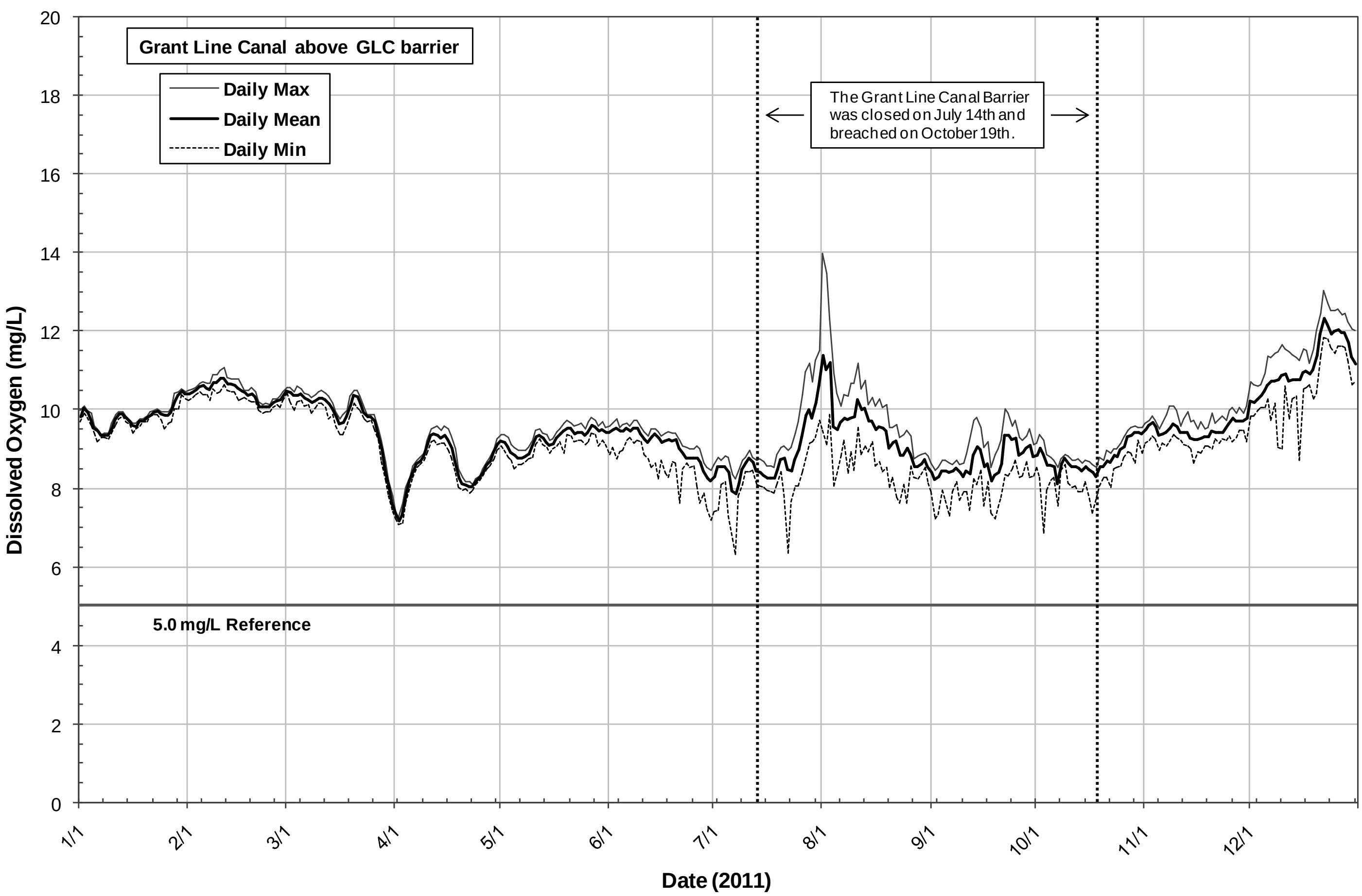
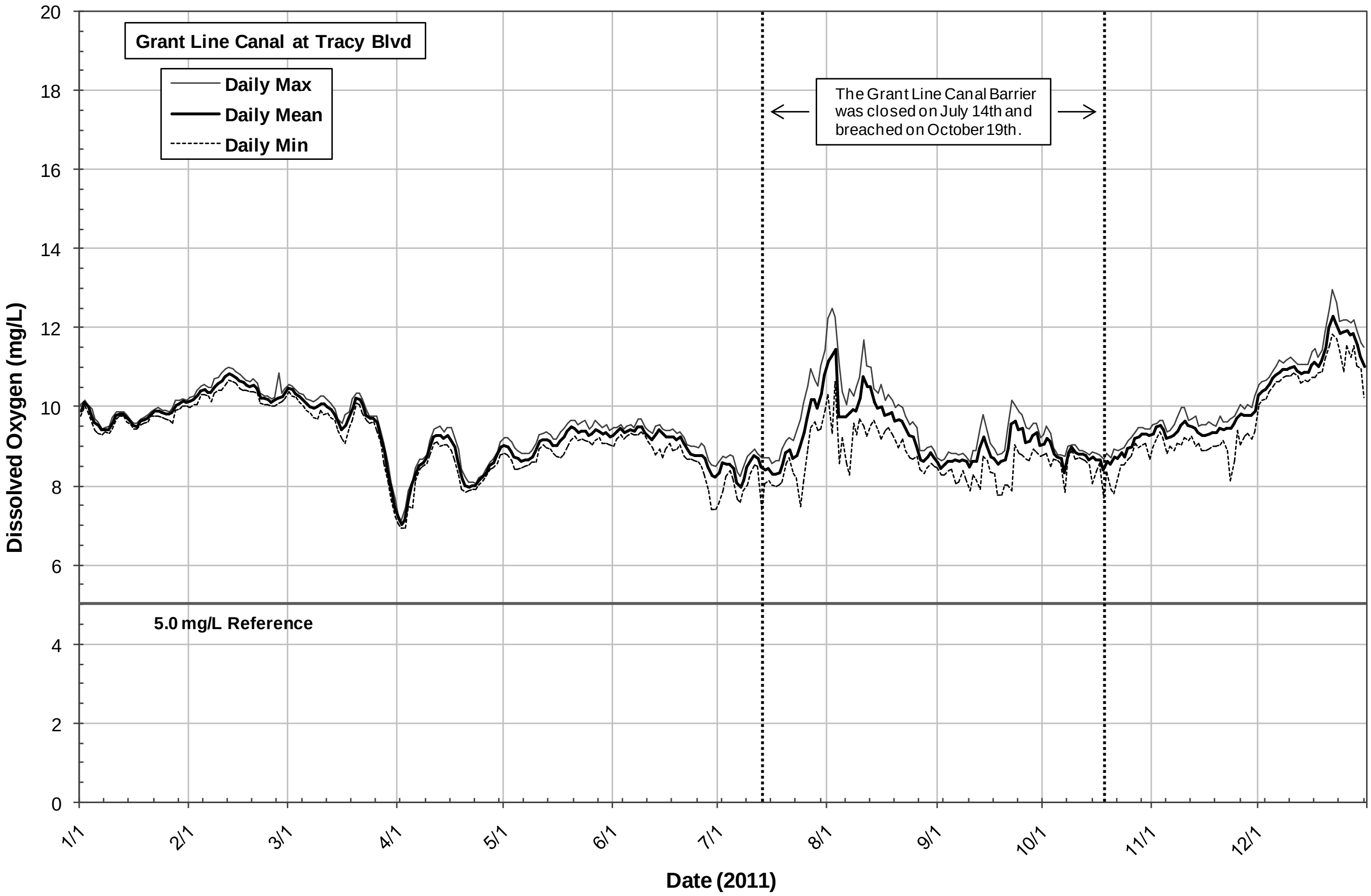


Figure 6-5: Daily Dissolved Oxygen time-series graphs for the Grant Line and Victoria Canal stations



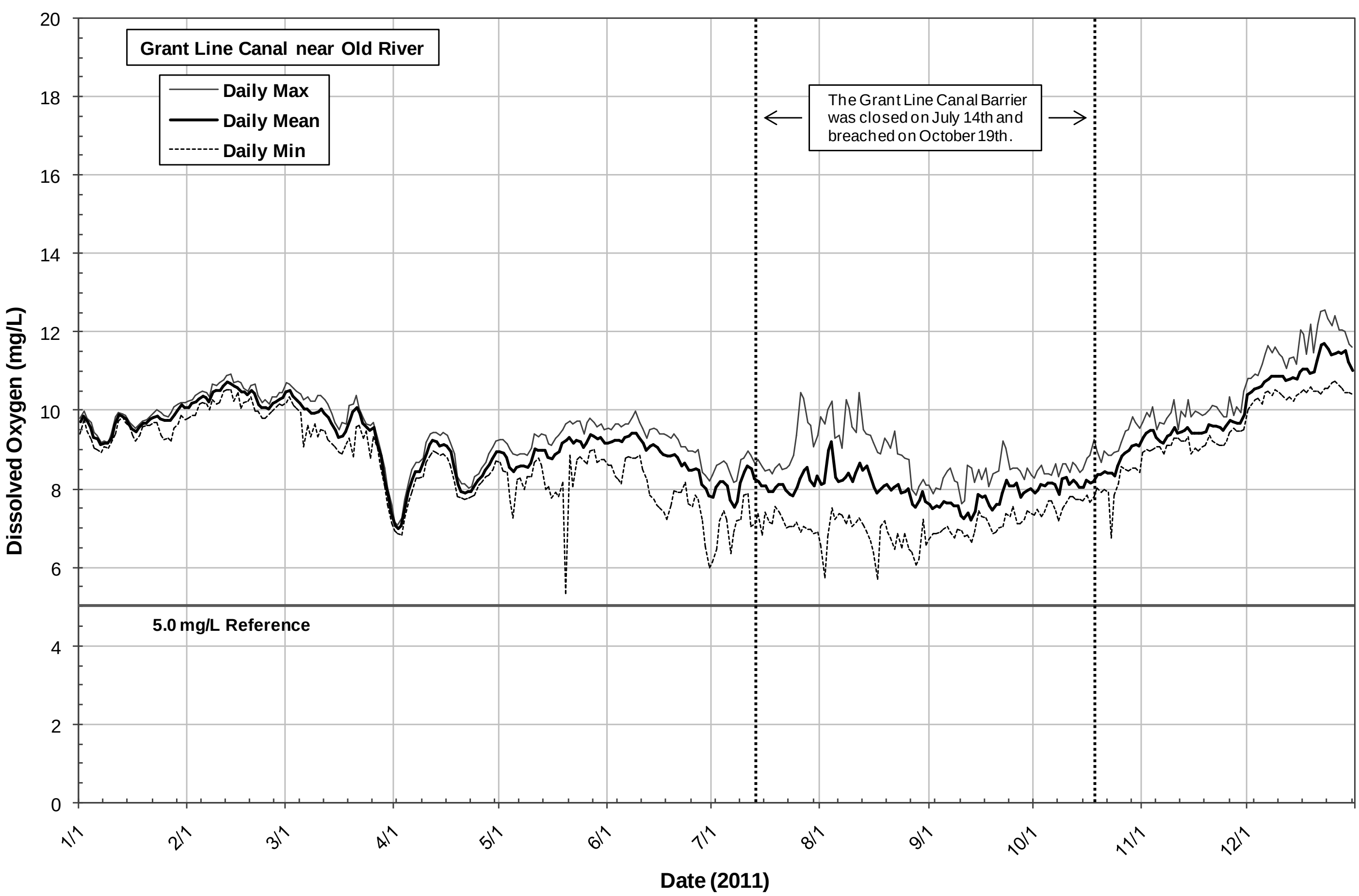


Figure 6-5: Daily Dissolved Oxygen time-series graphs for the Grant Line and Victoria Canal stations

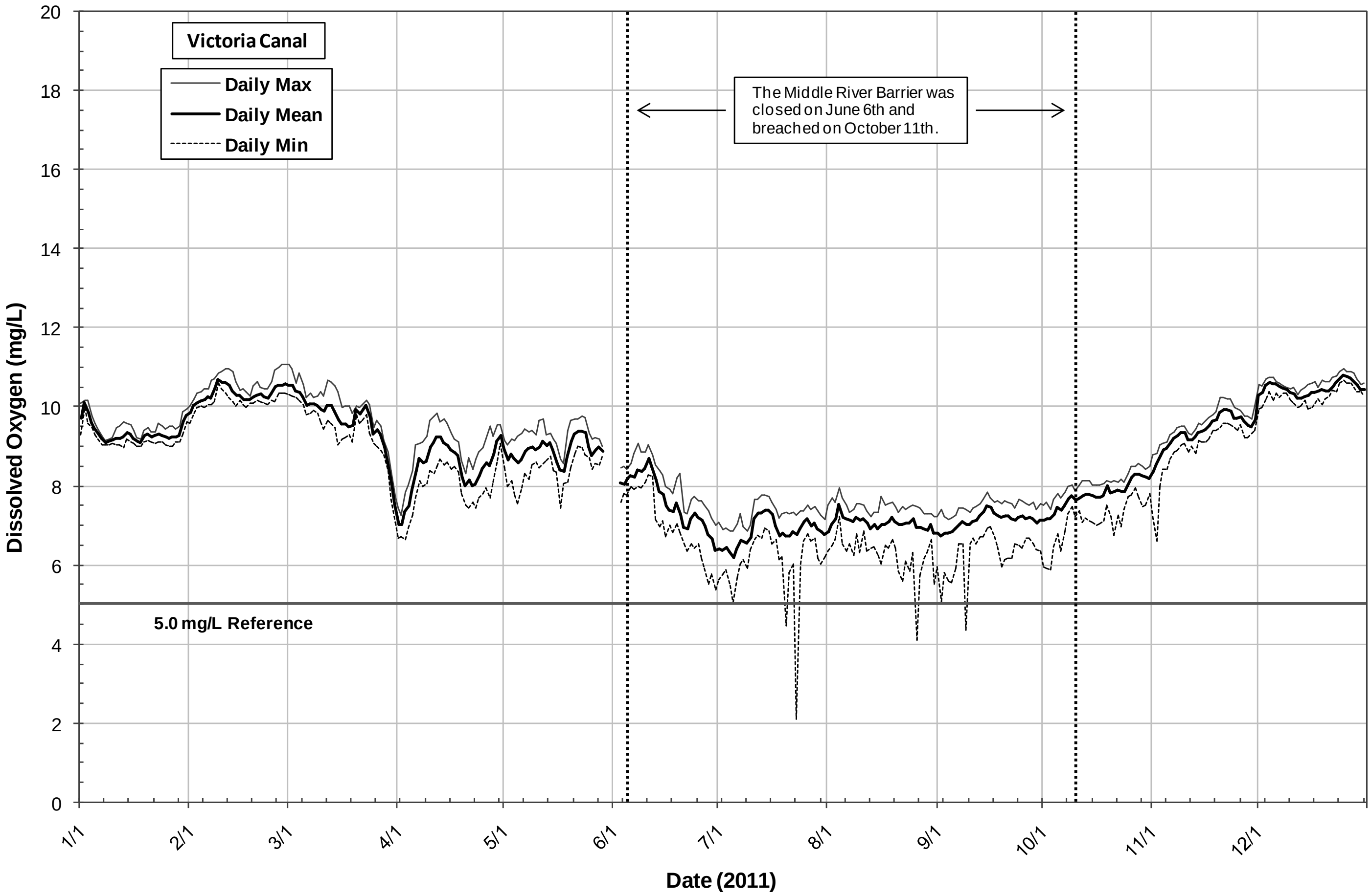
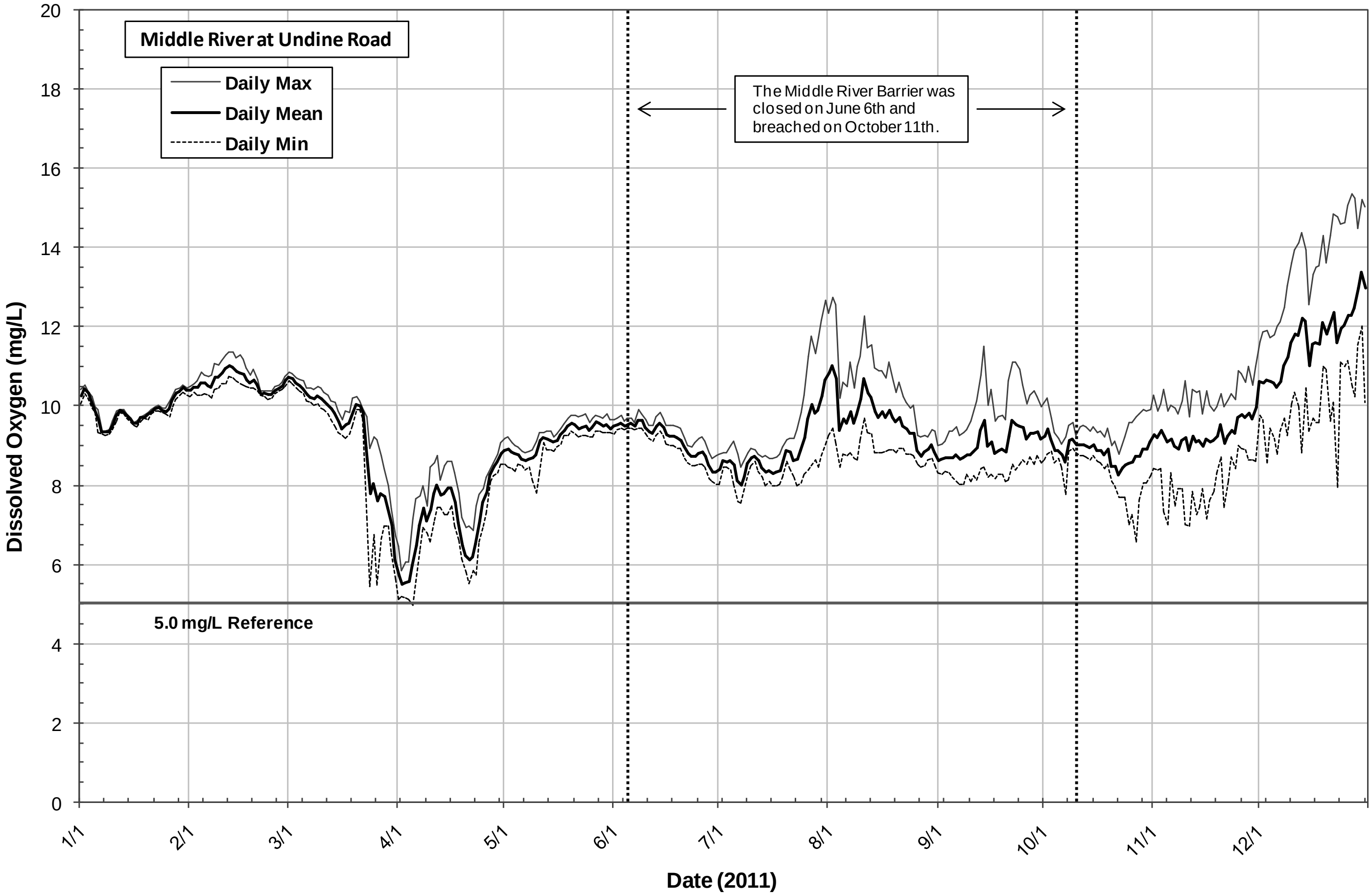


Figure 6-5: Daily Dissolved Oxygen time-series graphs for the Grant Line and Victoria Canal stations



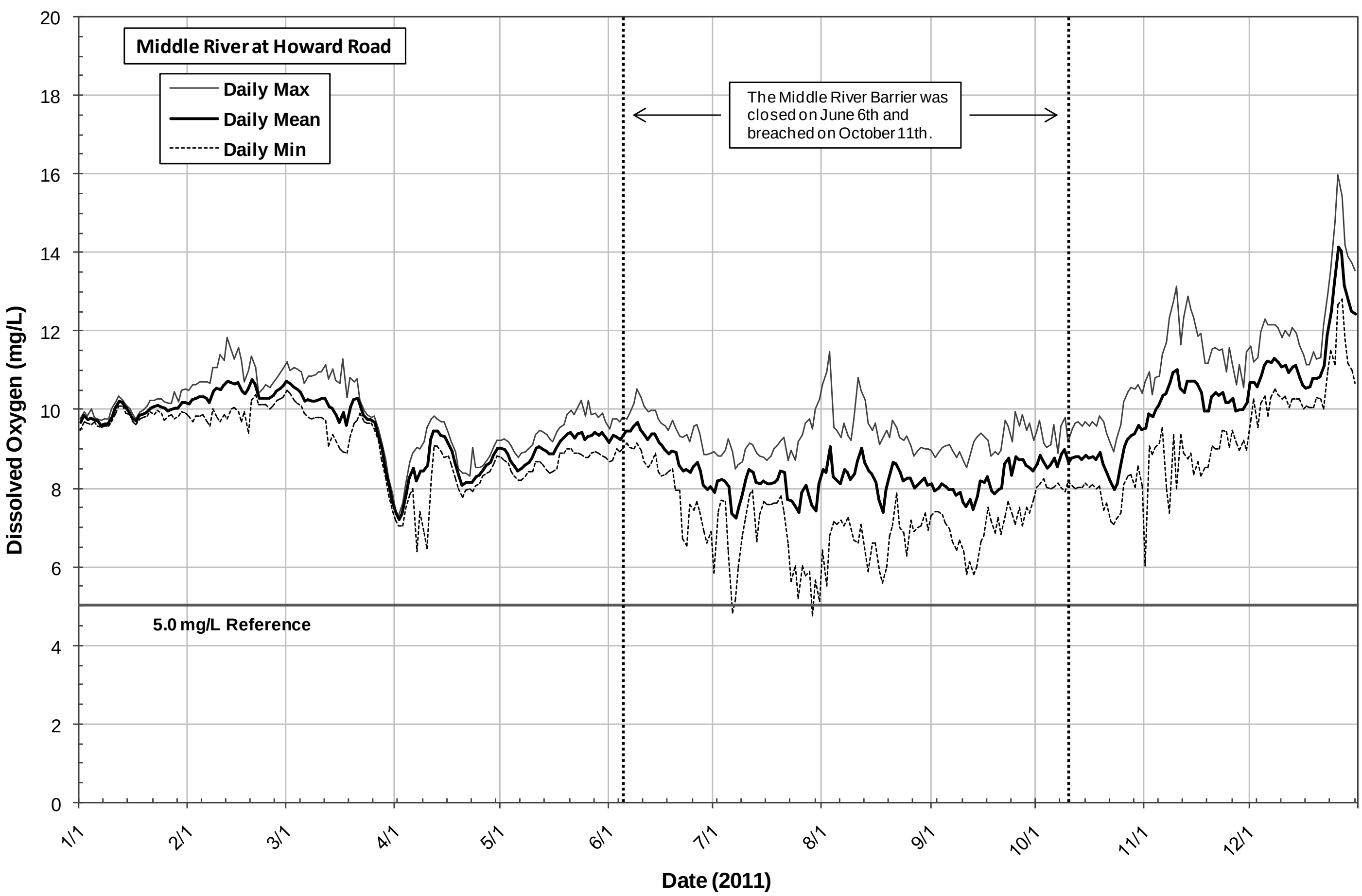
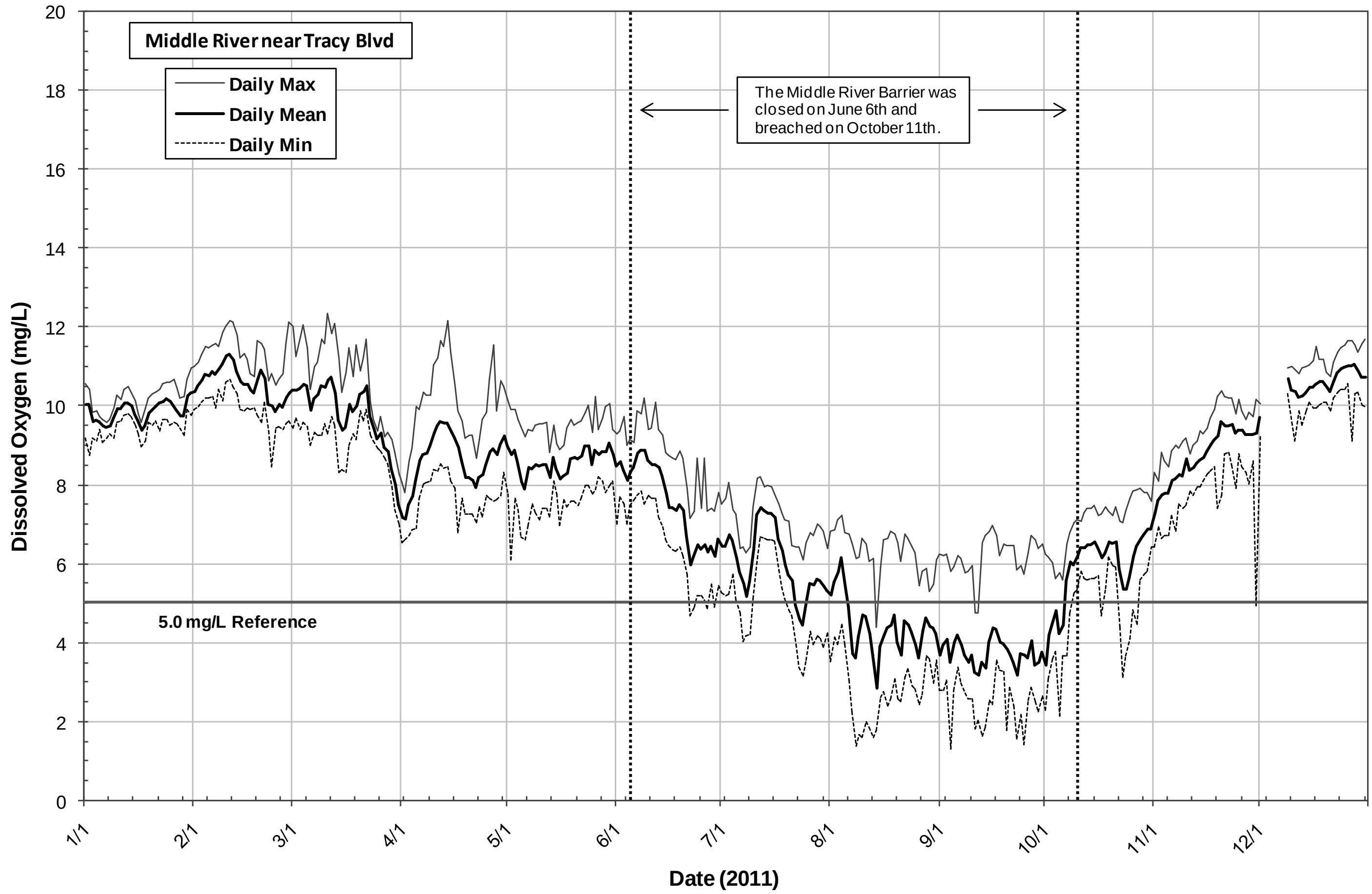


Figure 6-6: Daily Dissolved Oxygen time-series graphs for the Middle River stations



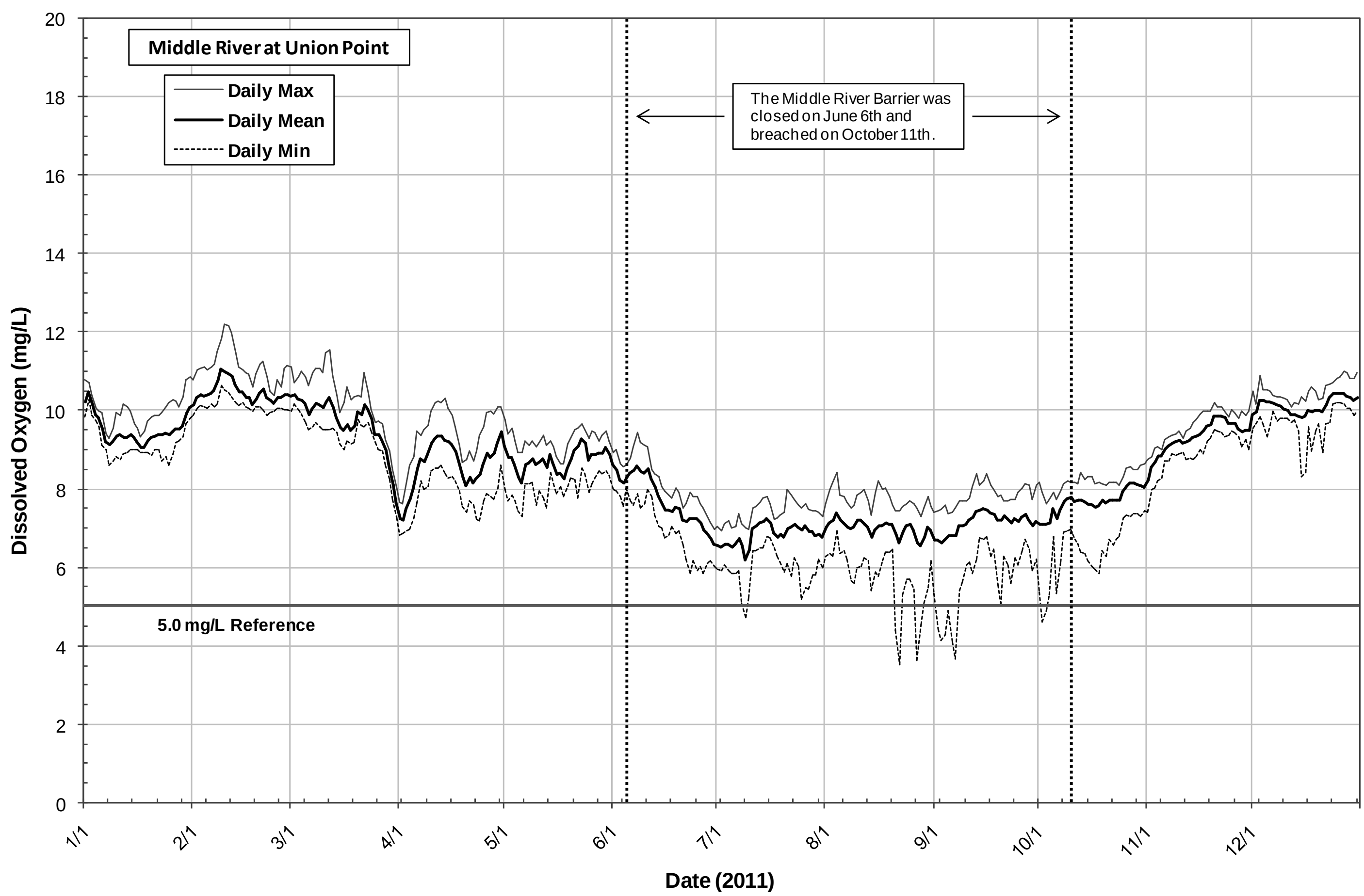
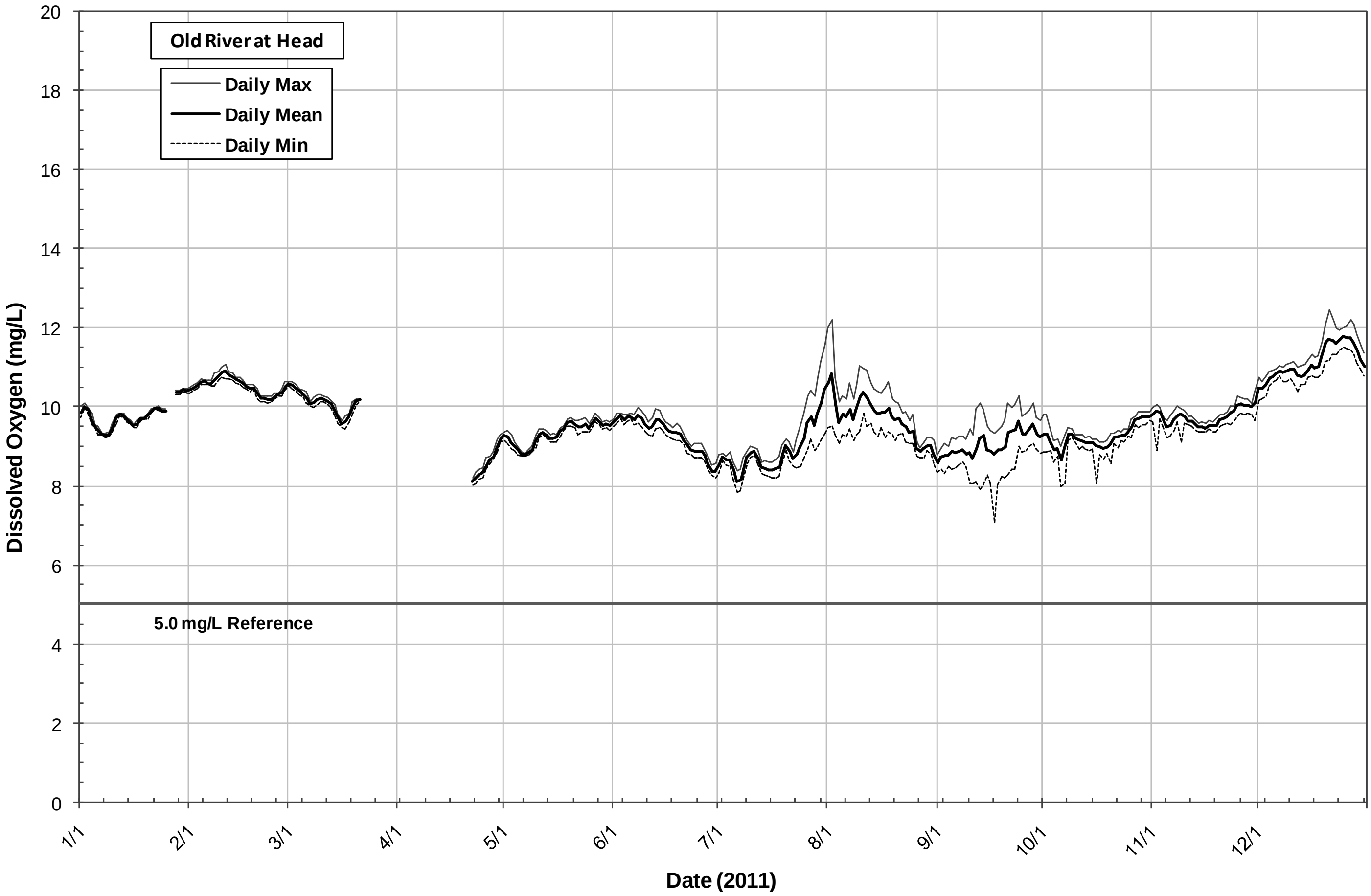


Figure 6-6: Daily Dissolved Oxygen time-series graphs for the Middle River stations



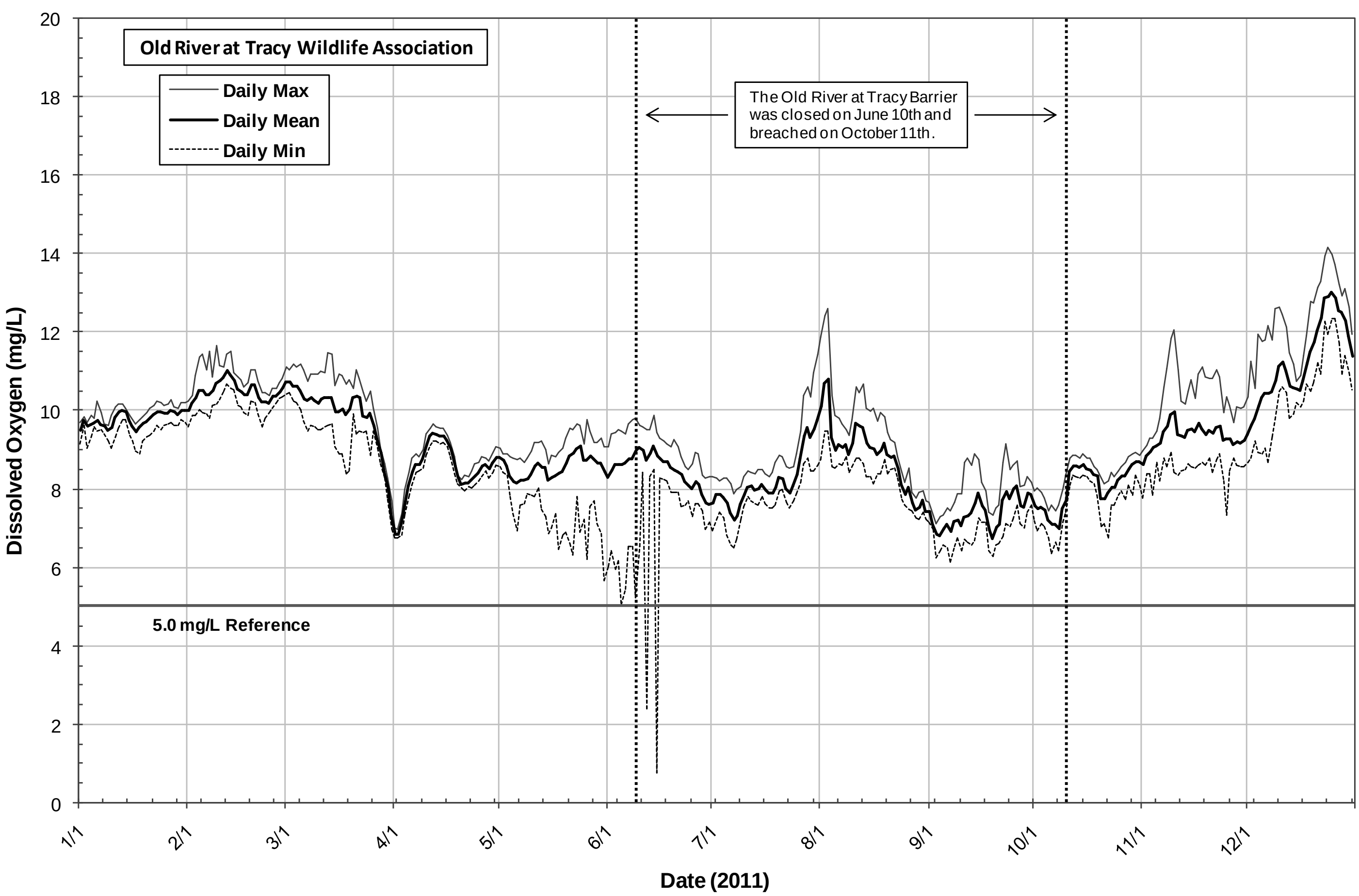
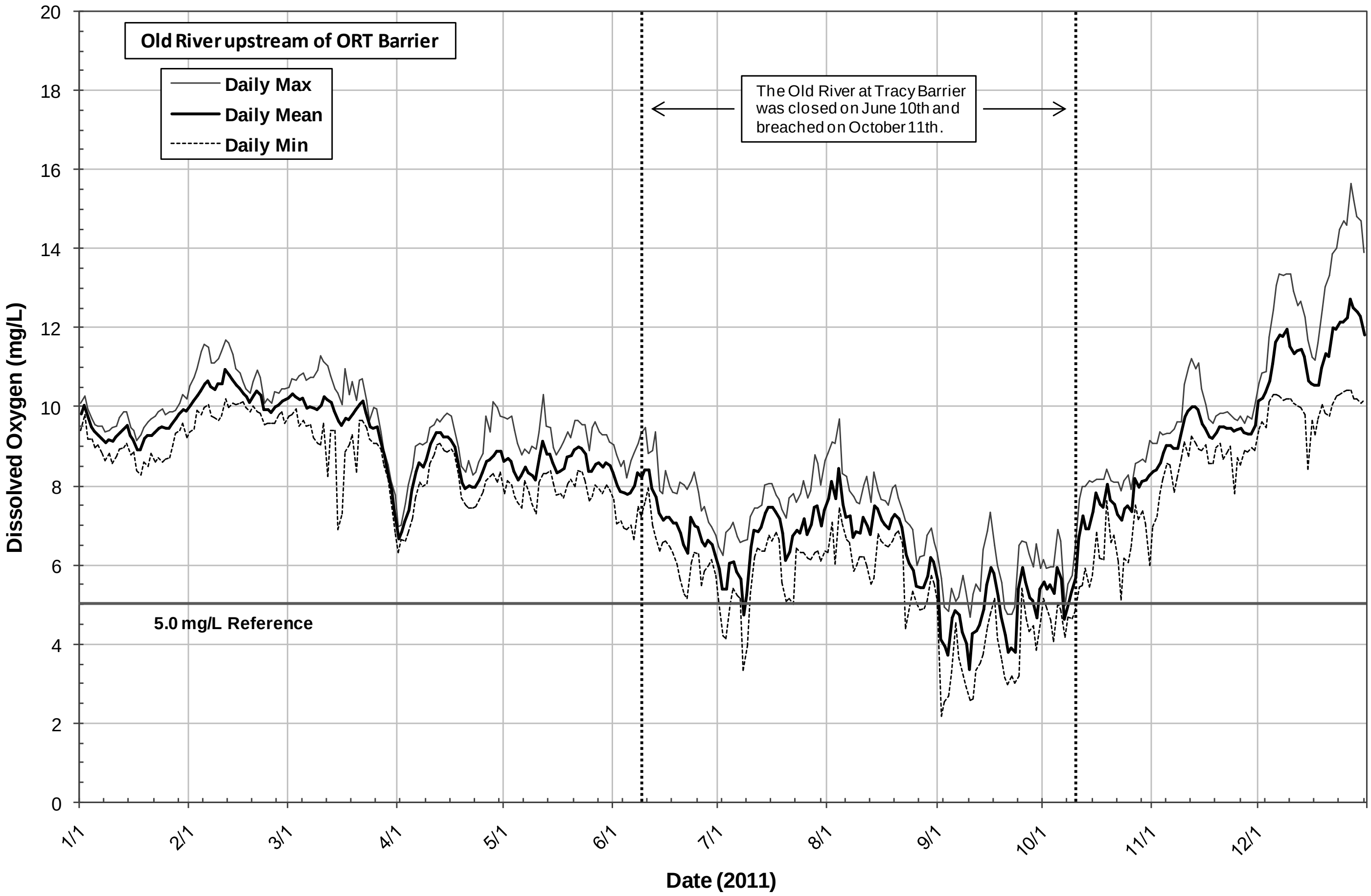


Figure 6-7: Daily Dissolved Oxygen time-series graphs for the Old River stations



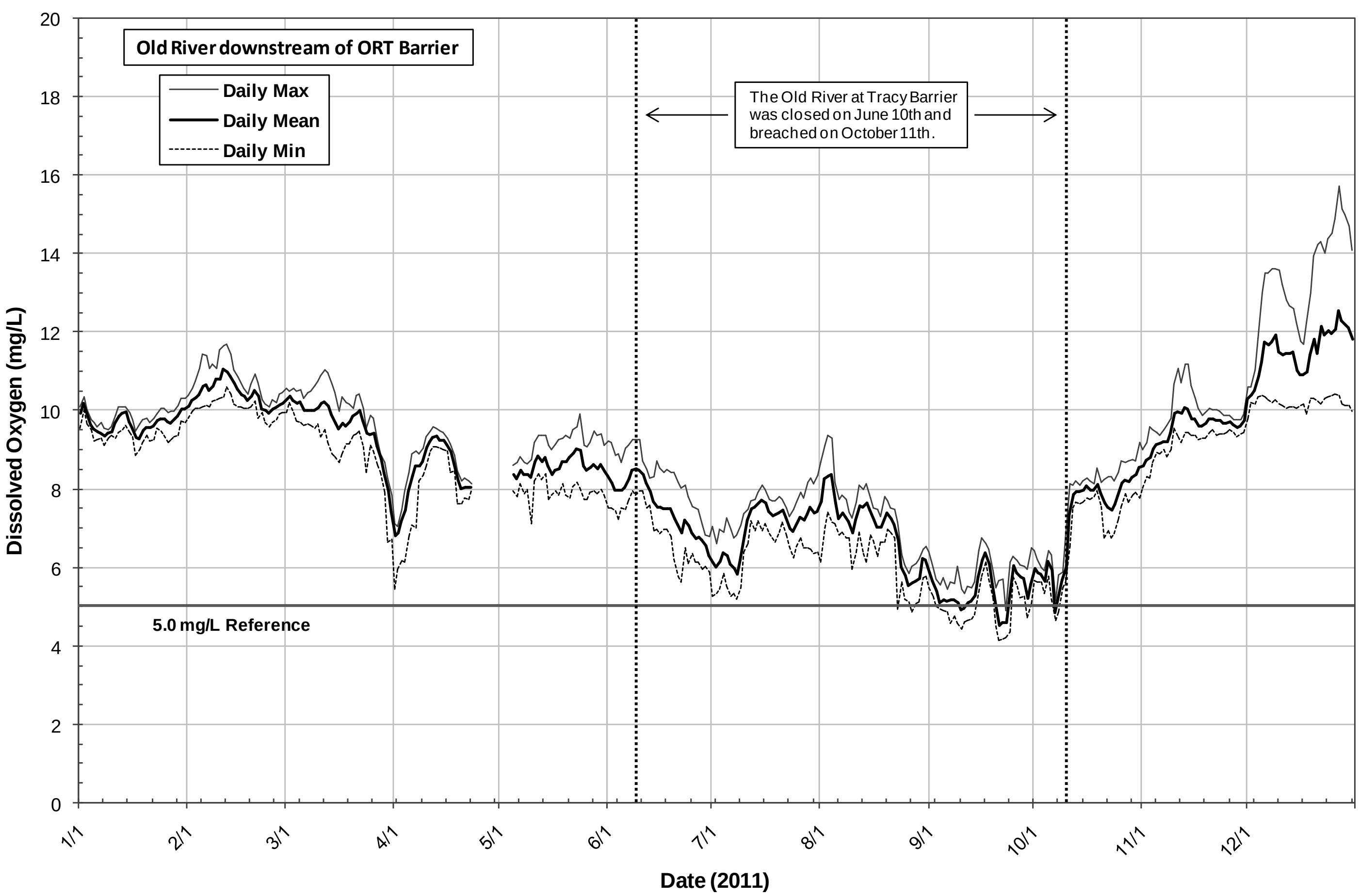
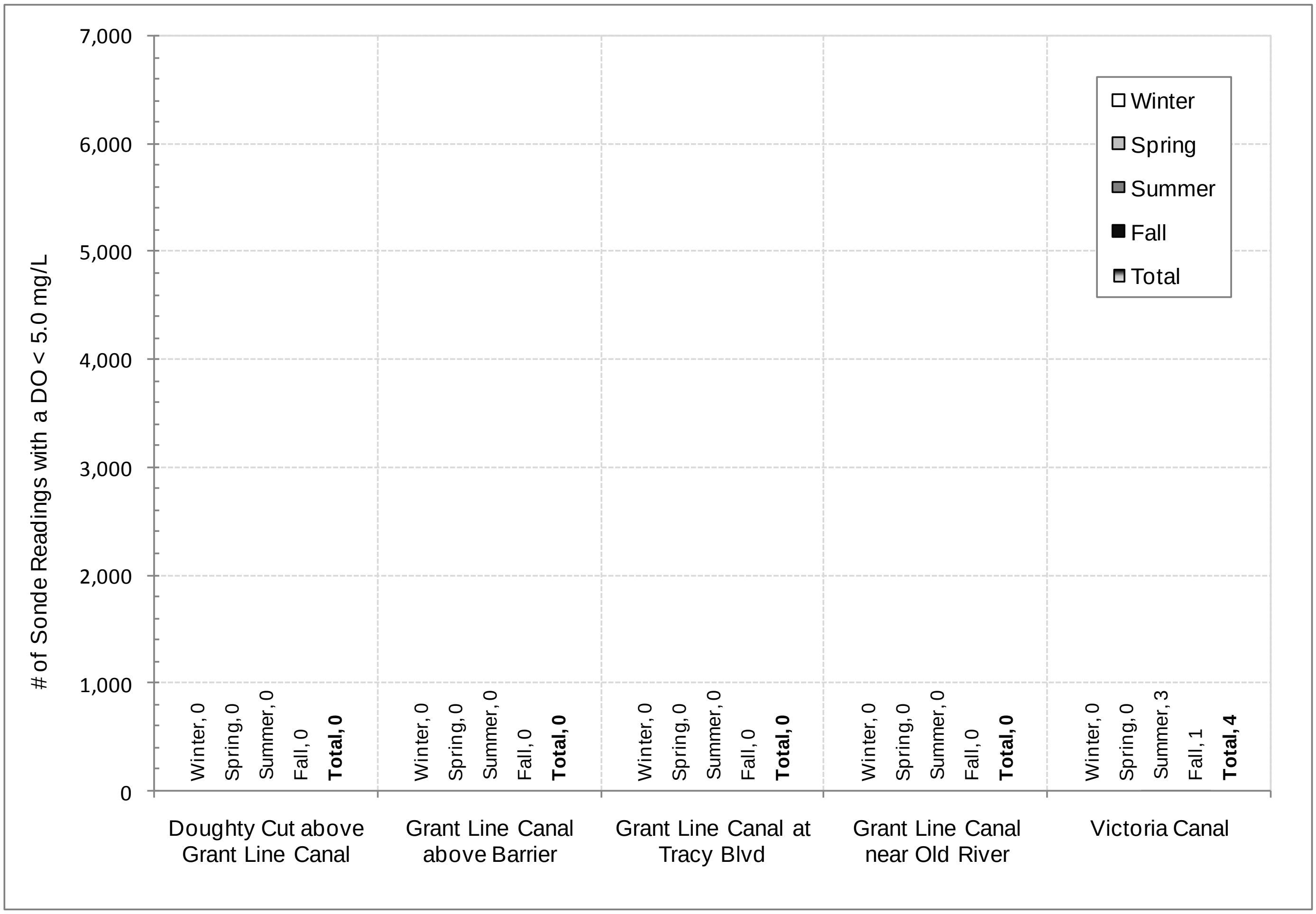


Figure 6-7: Daily Dissolved Oxygen time-series graphs for the Old River stations



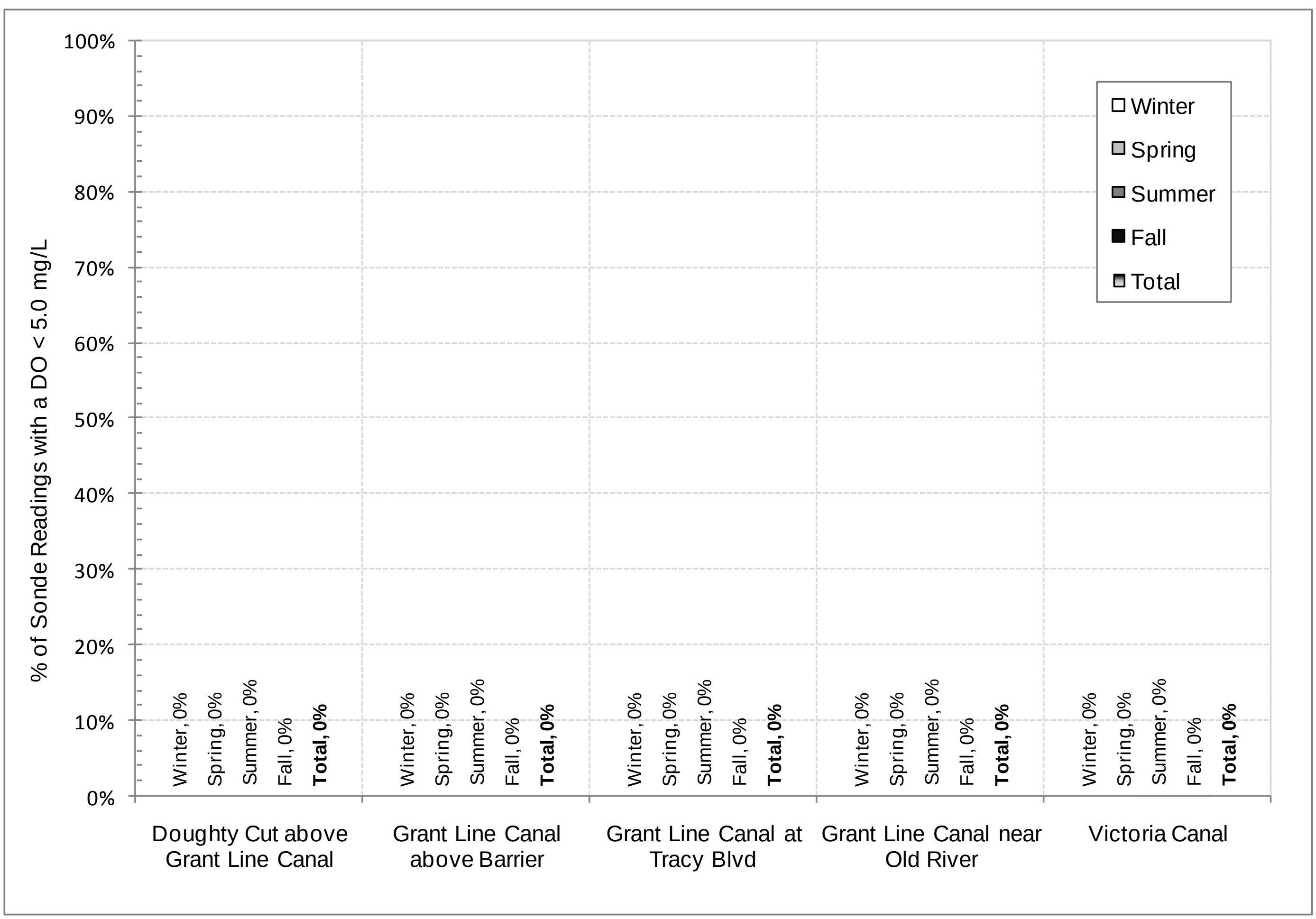


Figure 6-8: Dissolved Oxygen Standard Exceedences for the Grant Line and Victoria Canal stations

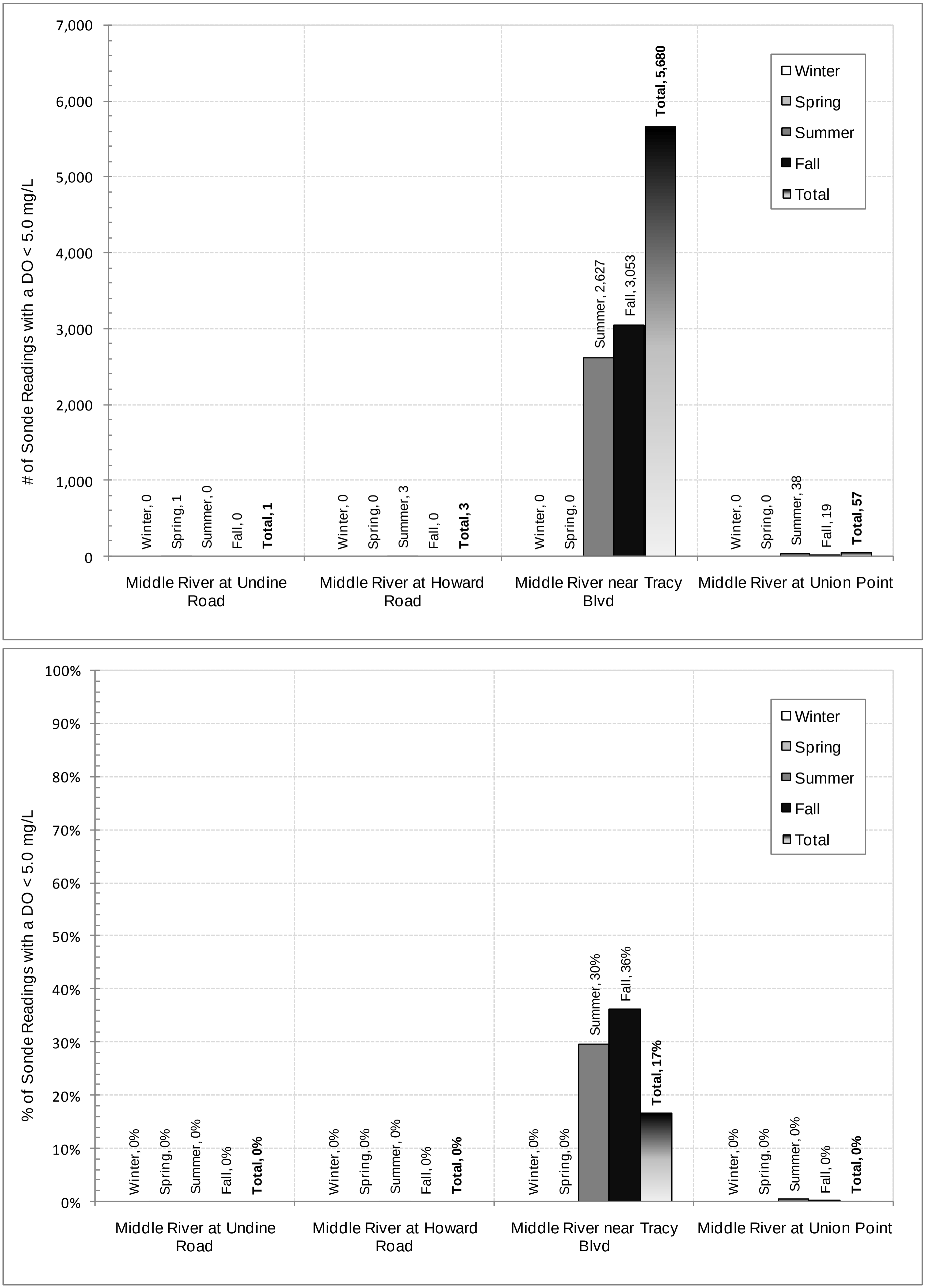
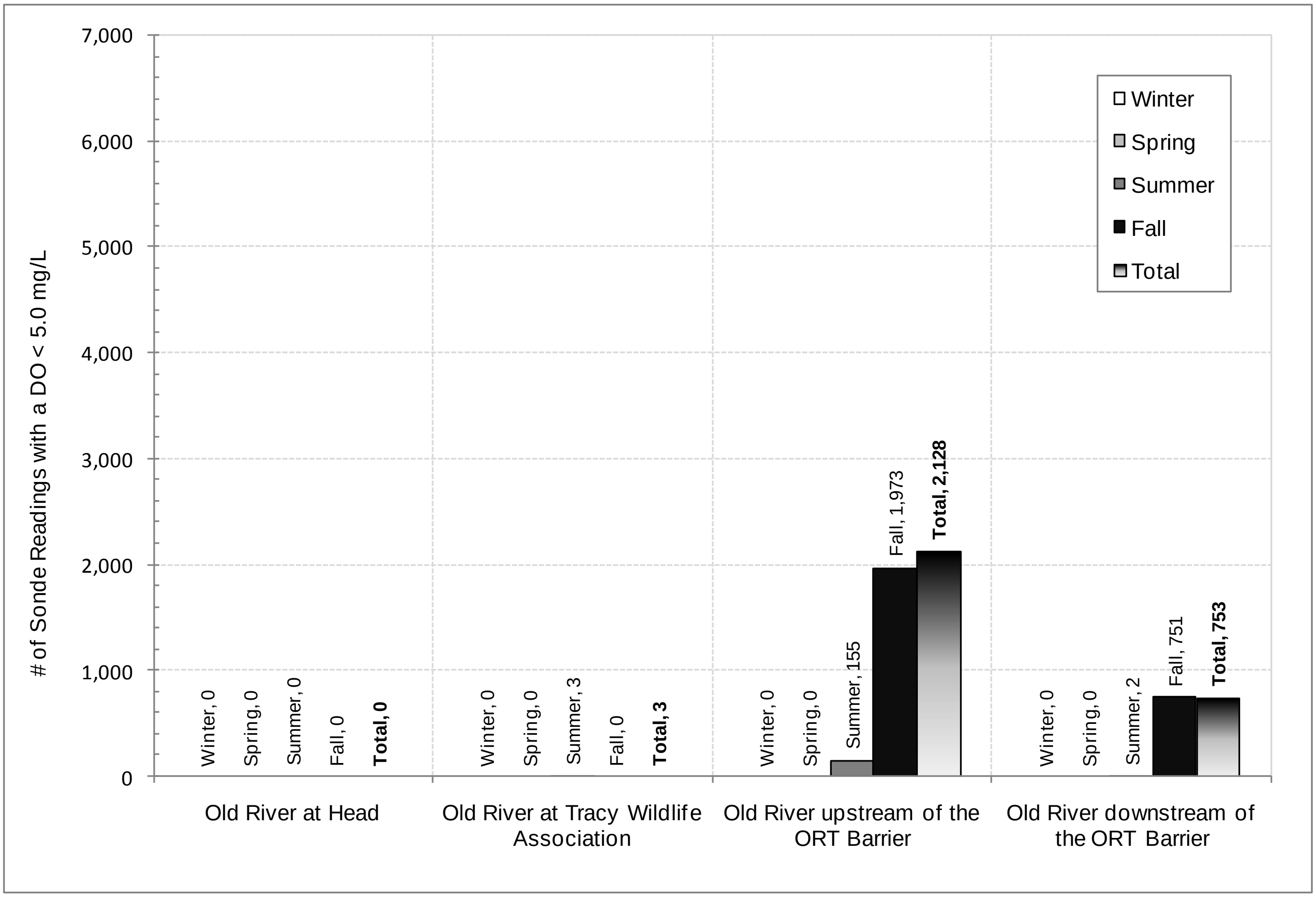


Figure 6-9: Dissolved Oxygen Standard Exceedences for the Middle River stations



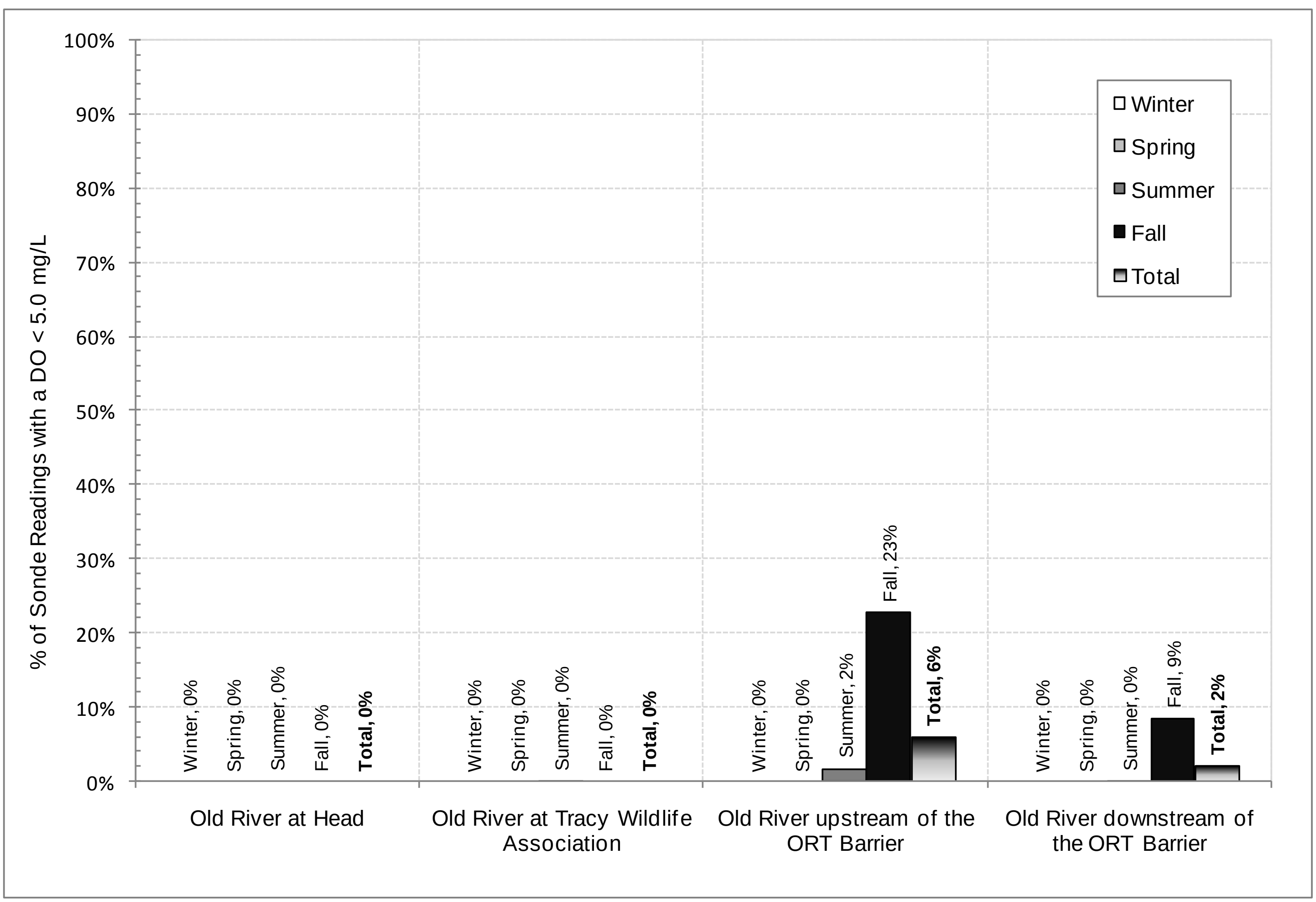


Figure 6-10: Dissolved Oxygen Standard Exceedences for the Old River stations

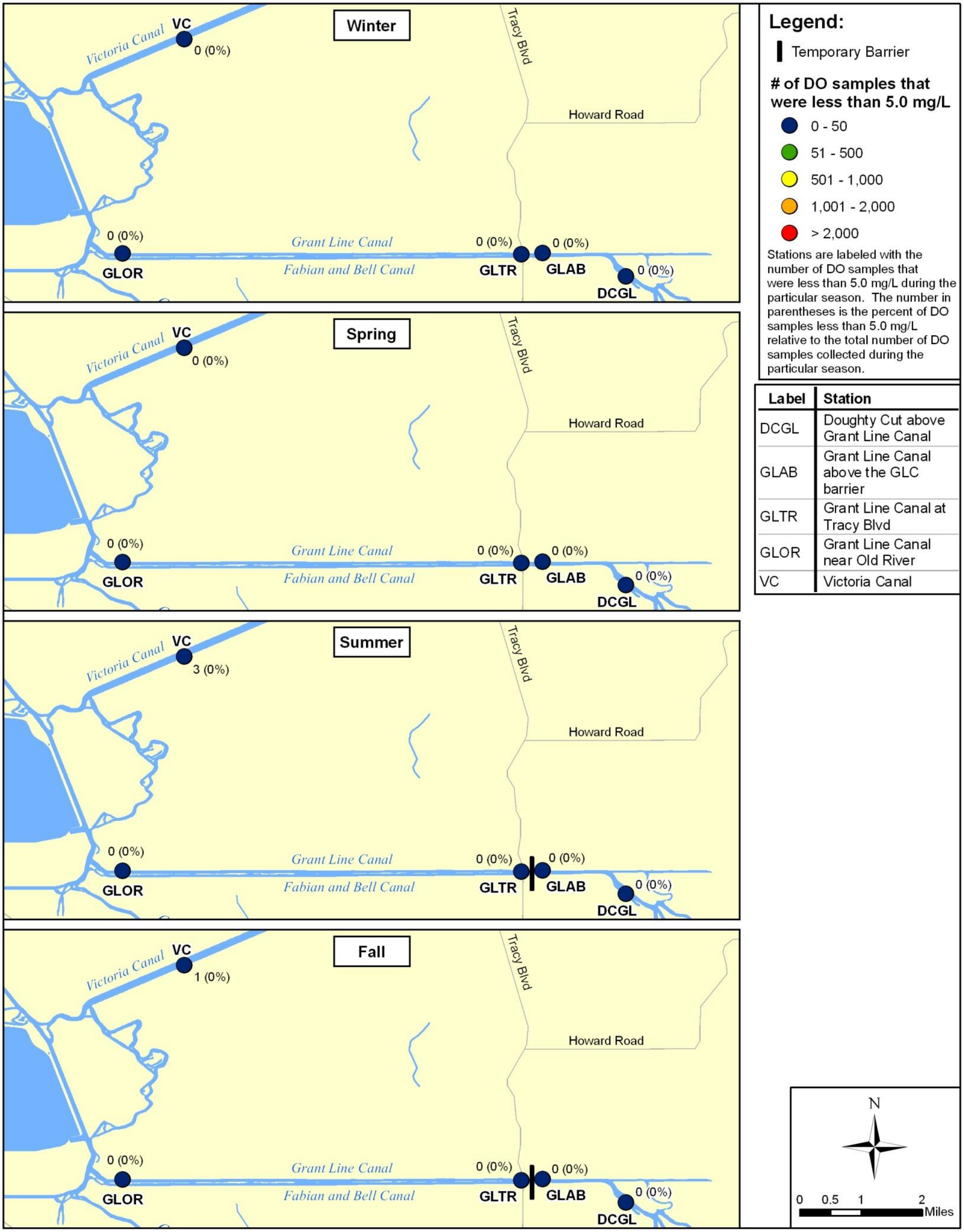


Figure 6-11: Map of Dissolved Oxygen Standard Exceedences for the Grant Line and Victoria Canal stations

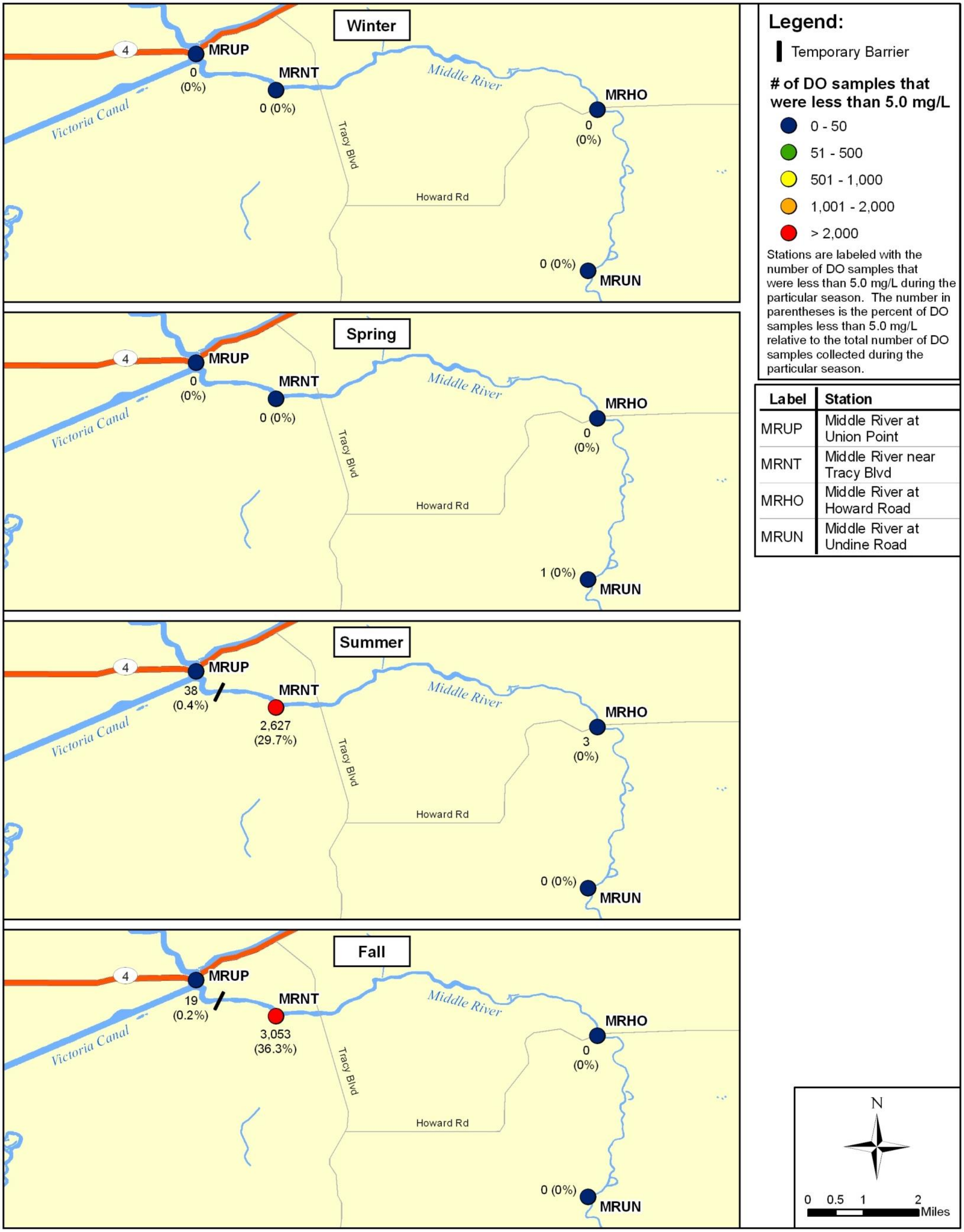


Figure 6-12: Map of Dissolved Oxygen Standard Exceedences for the Middle River stations

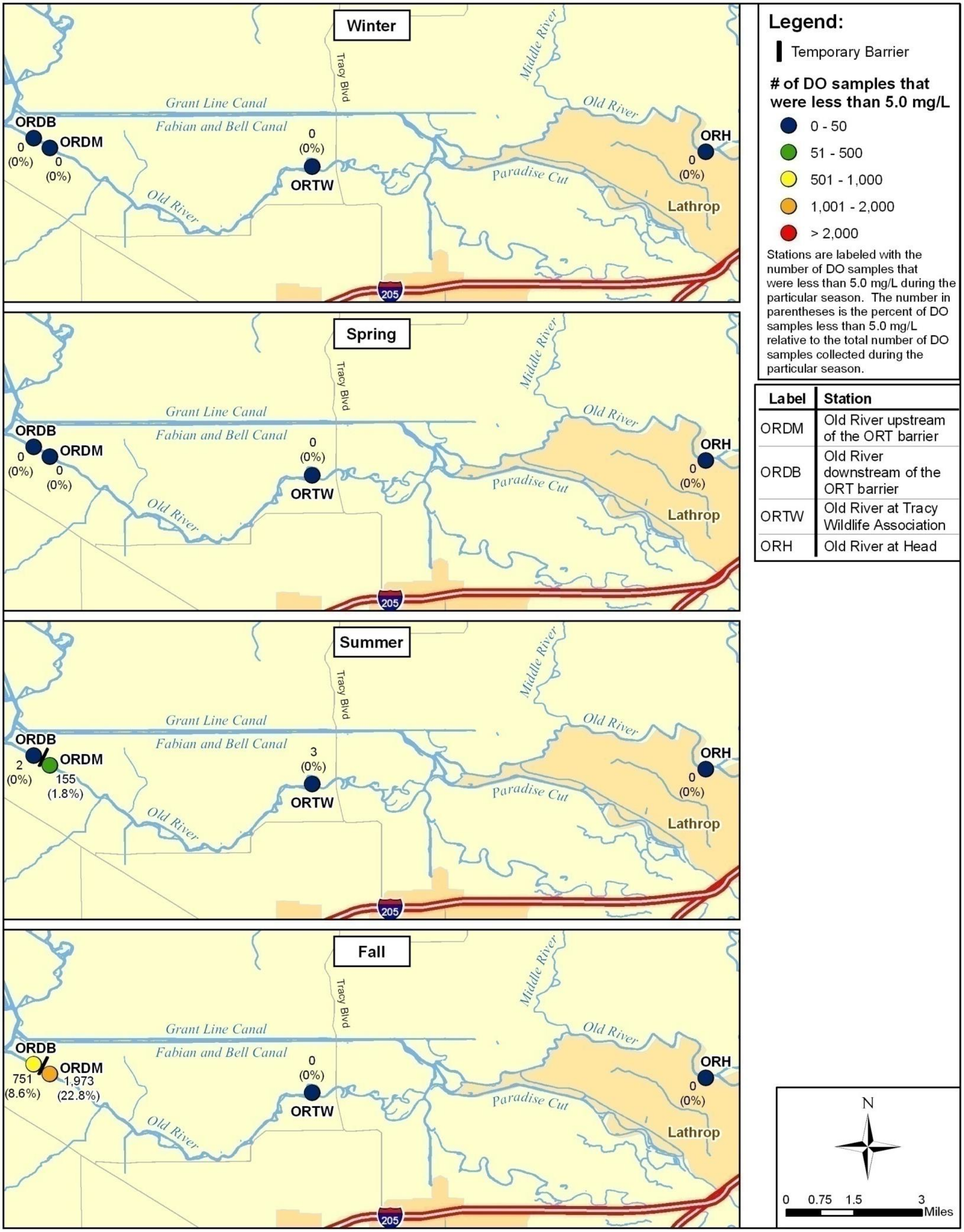


Figure 6-13: Map of Dissolved Oxygen Standard Exceedences for the Old River stations

pH

pH is a measure of the hydrogen ion concentration [H^+] of a solution. pH values range from 1 to 14 with values less than 7 considered acidic and values greater than 7 considered basic. Since the pH scale is logarithmic; a pH value of 7 is ten times greater than a pH value of 6 and one hundred times greater than a value of 5. Natural waters usually have pH values in the range of 4 to 9, and most are slightly basic (APHA, 2005). Algal photosynthesis occurring in the water column can affect pH values. The process of photosynthesis consumes CO_2 from the water. Less CO_2 in the water decreases carbonic acid which makes the water more alkaline and increases the pH.

A maximum pH of 8.96 was recorded on August 1st at Grant Line Canal above the GLC barrier and a minimum of 6.59 was recorded on July 23rd at Middle River near Tracy Blvd (Tables 6-3 to 6-6). Figures 6-14, 6-15, and 6-16 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively.

Typically, at the South Delta stations there is a noticeable increase in pH values during the spring months that is associated with increasing rates of photosynthesis; however during 2011 no such trend was obvious (Figures 6-14 to 6-16). This could be partially due to the extremely wet winter and spring in early 2011. Also, chlorophyll *a* levels were relatively low at most stations during the spring indicating that rates of algal photosynthesis did not significantly increase during this time (Figures 6-29, 6-30, and 6-31). Monthly average pH values during the spring (March – May) ranged from 6.96 in April at Middle River at Undine Road to 8.18 in March at Old River at Head (Tables 6-3 to 6-6).

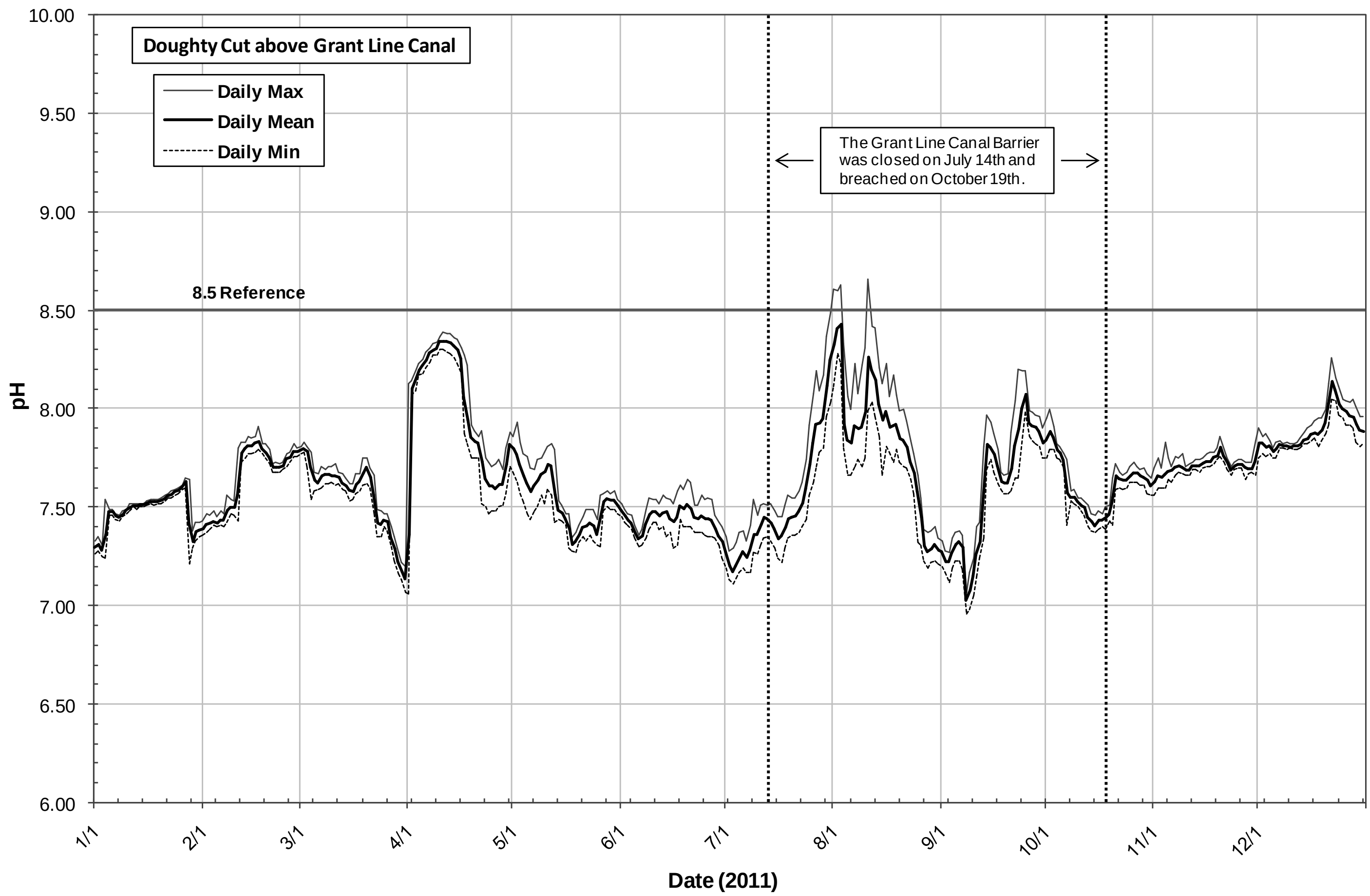
At some of the South Delta stations, pH values were higher and more variable from mid-July to the beginning of September and from mid-September to mid-October. This trend was more apparent at the stations that had higher chlorophyll *a* concentrations during the summer and early fall (Figures 6-29, 6-30, and 6-31). Monthly average pH values during the summer and early fall (July – October) ranged from 6.89 in September at Middle River near Tracy Blvd to 7.82 in August at Grant Line Canal at Tracy Blvd (Tables 6-3 to 6-6).

At most of the stations the pH values started to slowly increase at the end of the year in 2011 (Figures 6-14 to 6-16). Simultaneously, the chlorophyll *a* concentrations at most of the stations began to increase at about the same time period (Figures 6-29, 6-30, and 6-31). During November and December of 2011, monthly average pH values ranged from 7.36 at Grant Line Canal near Old River to 7.99 at Middle River at Undine Road (Tables 6-3 to 6-6).

Water Quality Standard Exceedences:

As discussed in the Methods and Results section, the established pH criteria is 8.50 units; therefore, staff considered any pH sample of reliable data quality greater than 8.50 as exceeding the standard. Figures 6-17, 6-18, and 6-19 illustrate the number of pH readings with concentrations greater than 8.50 for each season and the overall total for the 2011 monitoring period for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively. In addition, the figures show the percent of sonde samples exceeding the pH standard relative to the total number of samples collected. Figures 6-20, 6-21, and 6-22 provide the exceedence information in a map format allowing for the observation of geographical relationships.

All of the South Delta stations had very low numbers of pH standard exceedences in 2011. The station with the most pH exceedences during 2011 was Old River upstream of the ORT barrier with a total of 744 (2.1% of the total number of samples). For comparison, seven of the 13 South Delta stations had more than 744 pH exceedences during the year of 2010. In addition, the Old River at Head station had the highest number of pH exceedences in 2010 with 5,459, which is seven times more than the highest number in 2011. Three stations had no pH readings with values greater than 8.5 units during 2011: Grant Line Canal near Old River, Victoria Canal, and Middle River at Union Point. Generally, most stations had more pH exceedences during the summer and fall seasons in 2011; however, about half of the standard exceedences for the year at the Old River upstream of the ORT barrier station and all of the pH exceedences at the Old River downstream of the barrier station occurred at the end of December 2011.



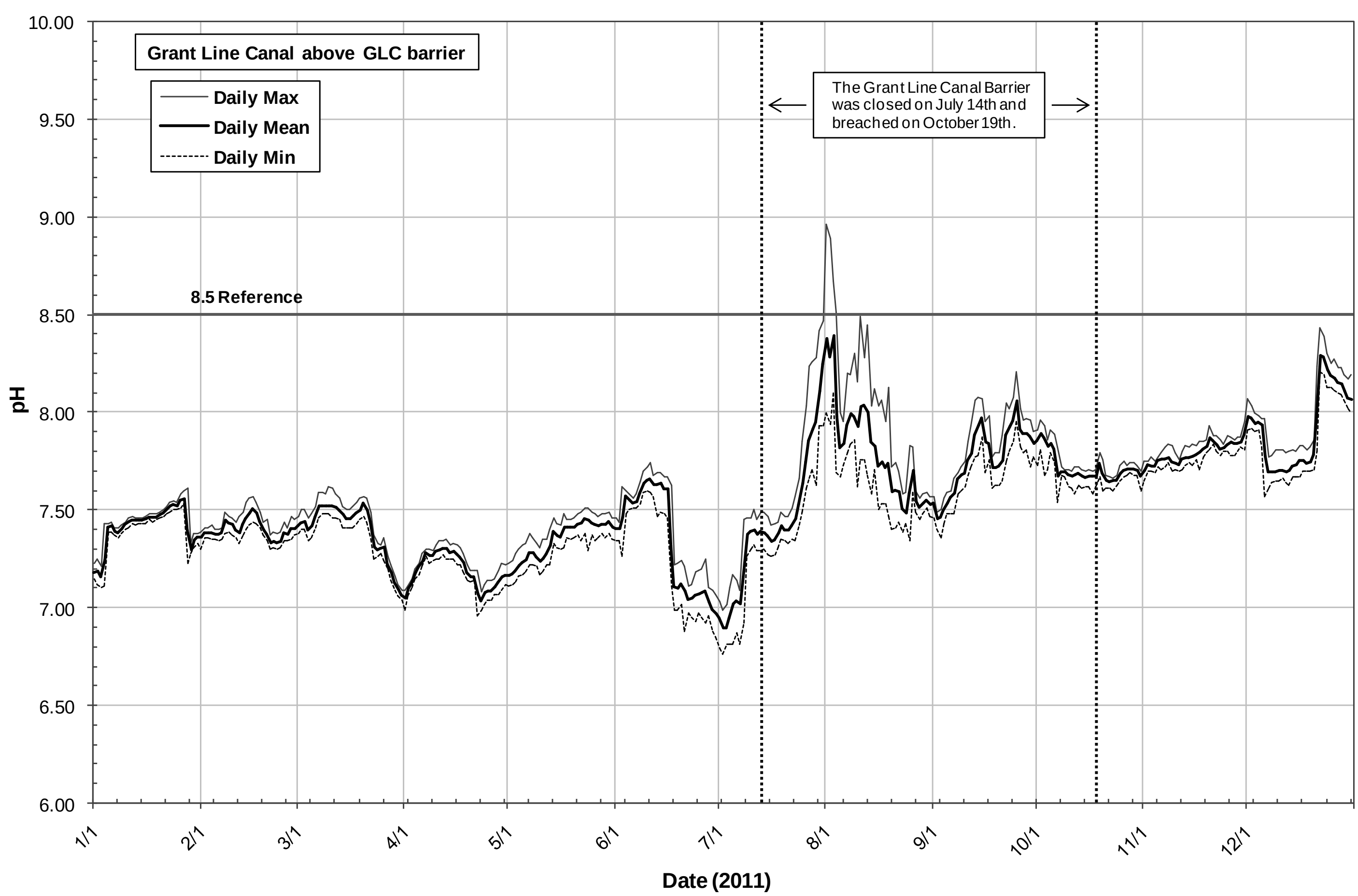
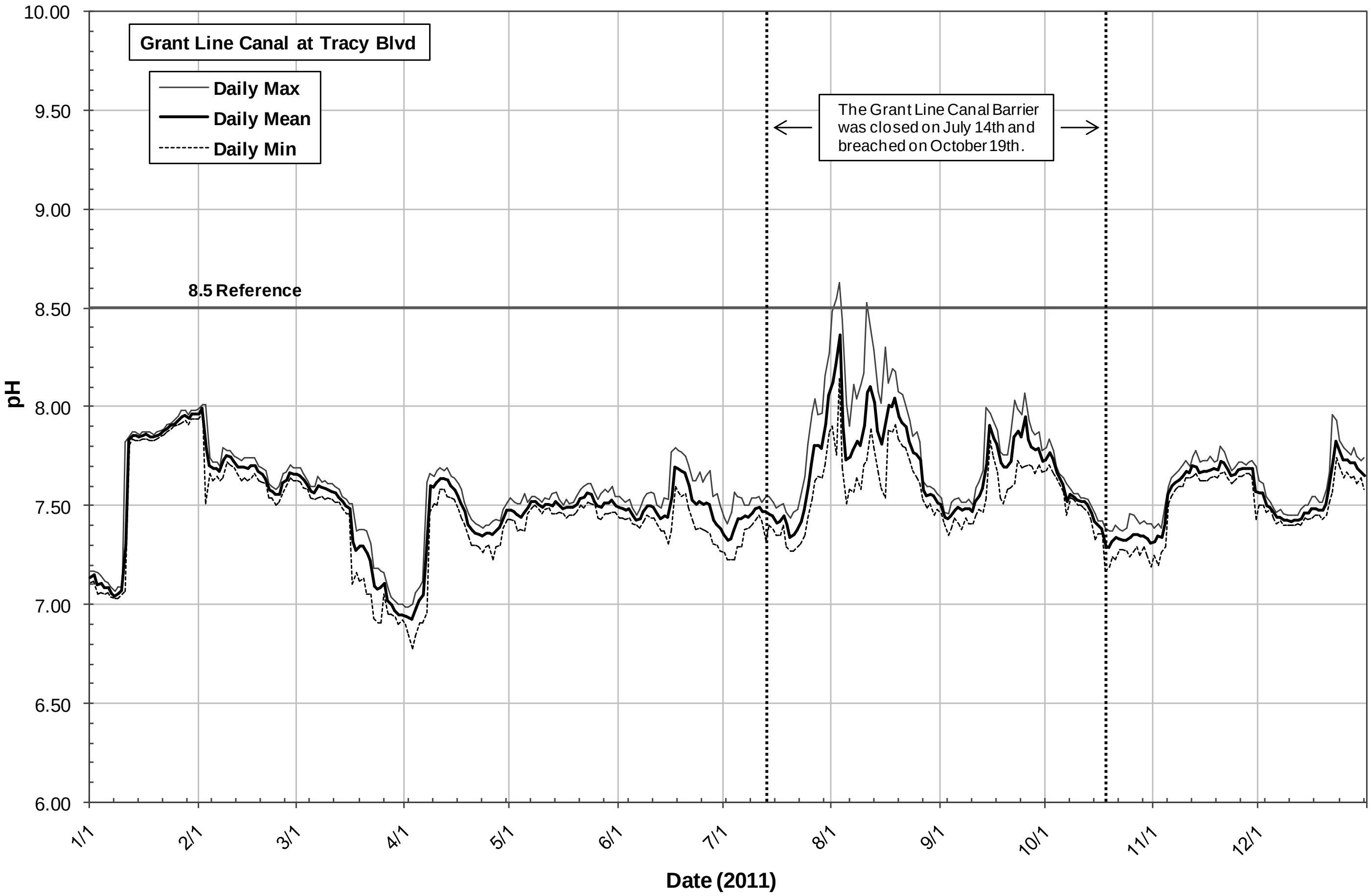


Figure 6-14: Daily pH time-series graphs for the Grant Line and Victoria Canal stations



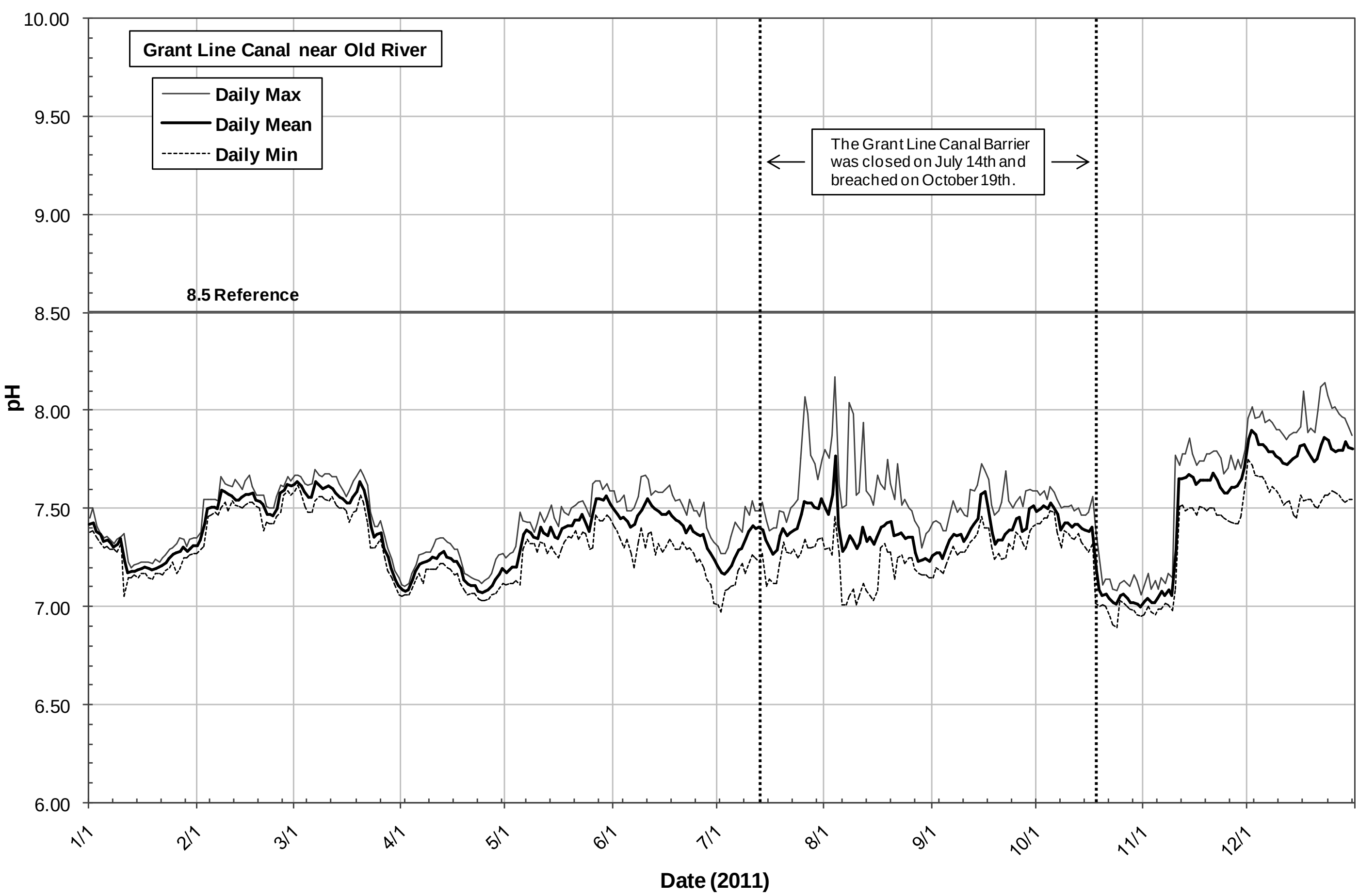


Figure 6-14: Daily pH time-series graphs for the Grant Line and Victoria Canal stations

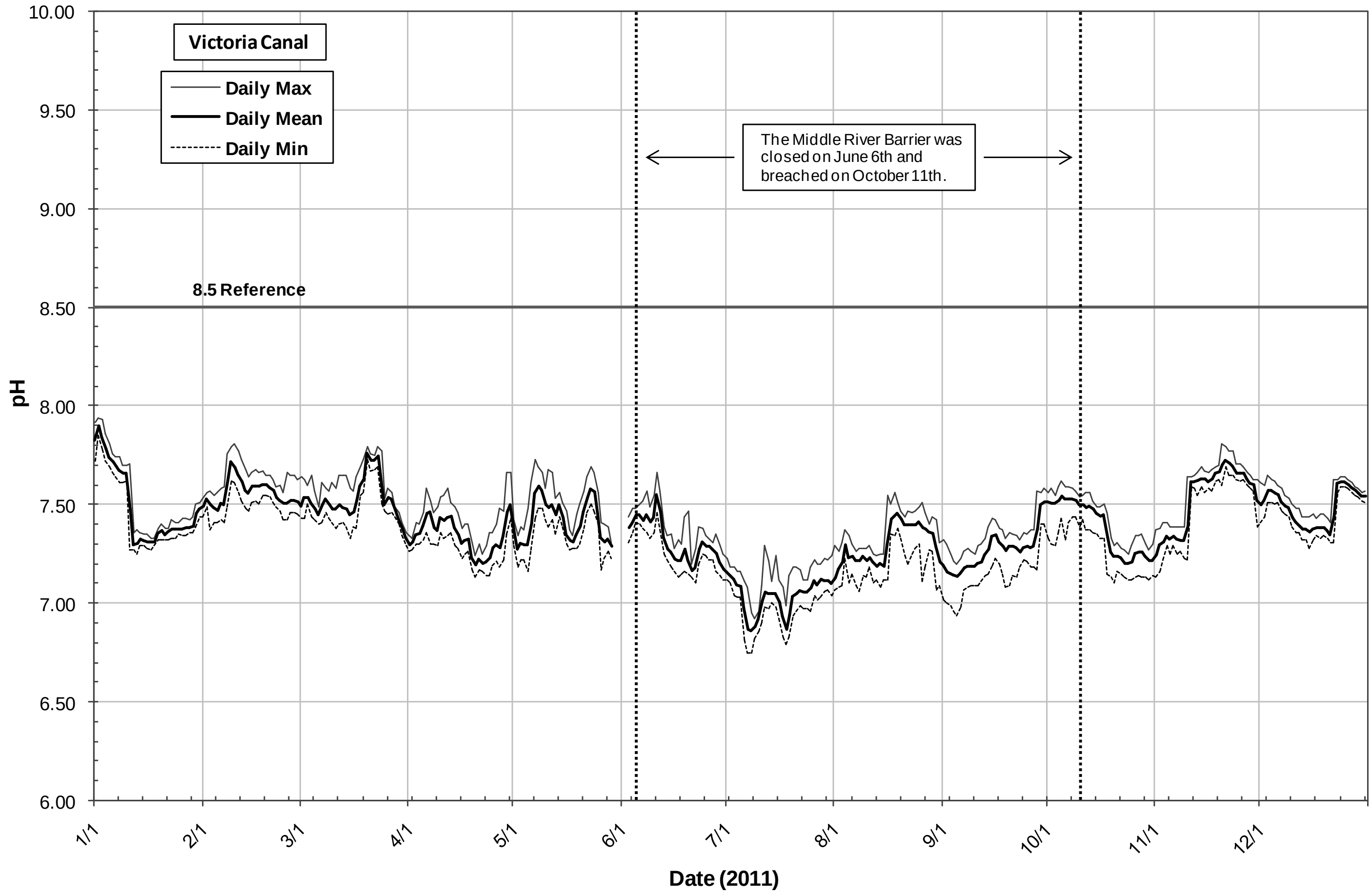
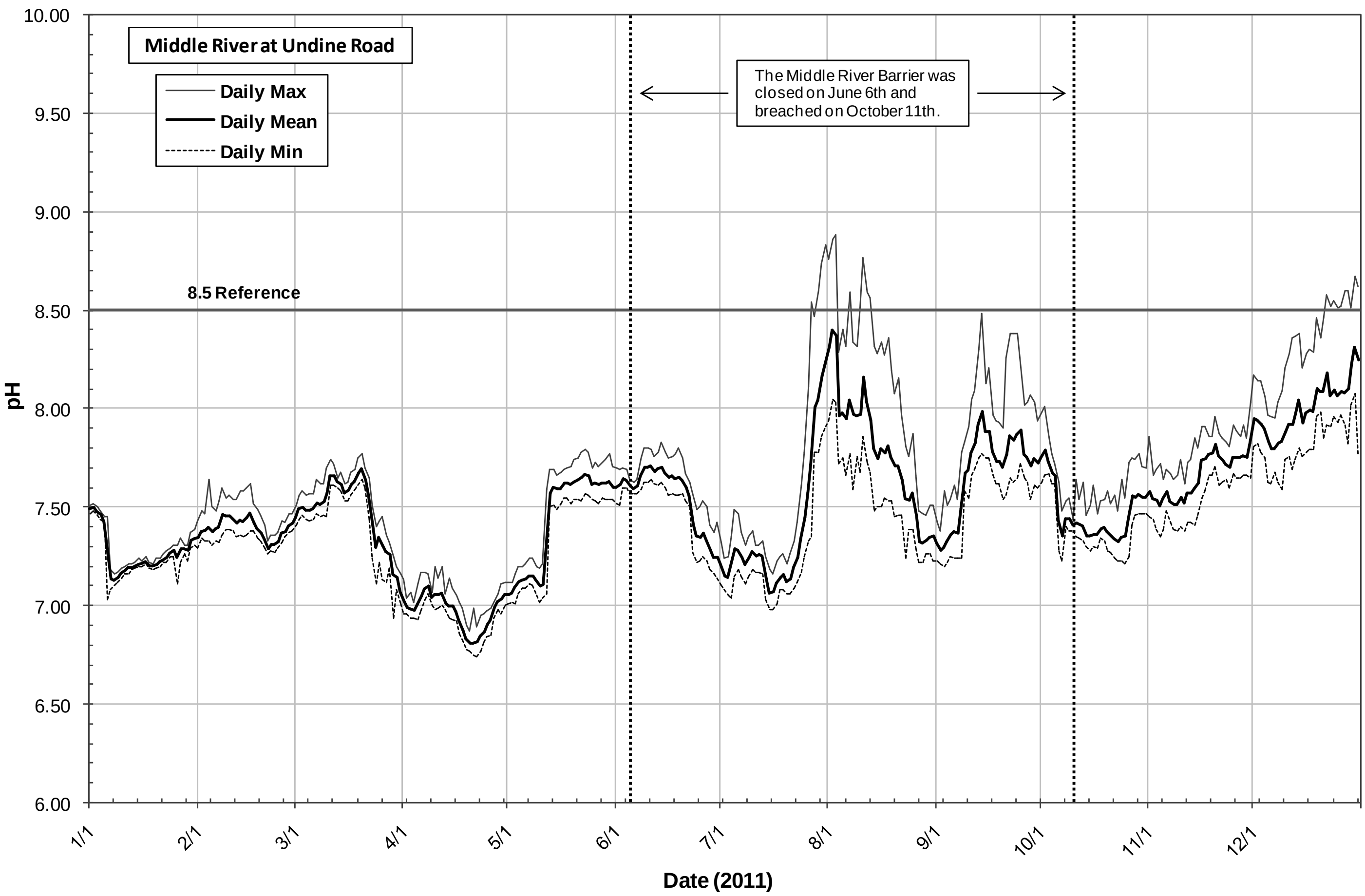


Figure 6-14: Daily pH time-series graphs for the Grant Line and Victoria Canal stations



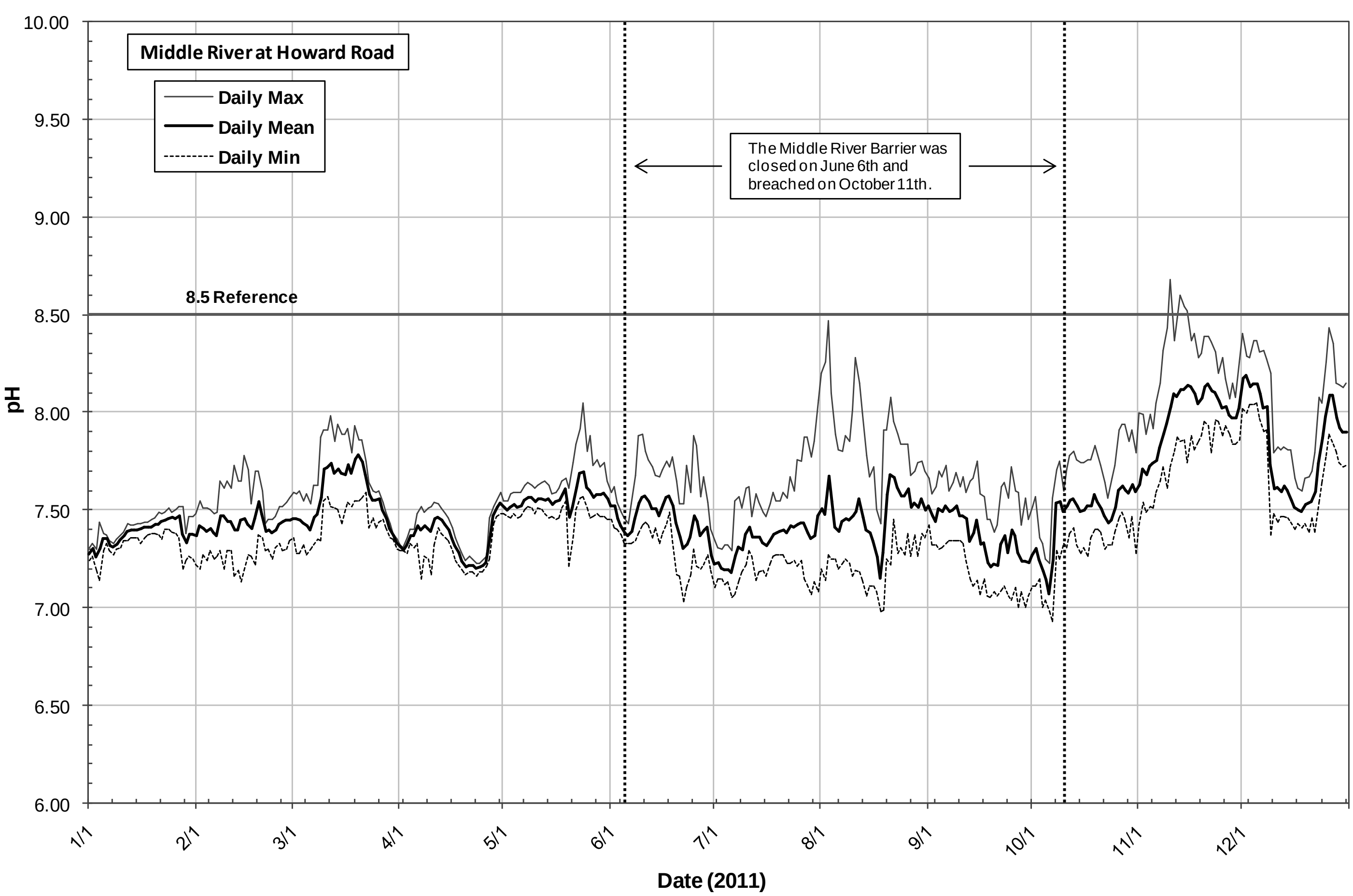
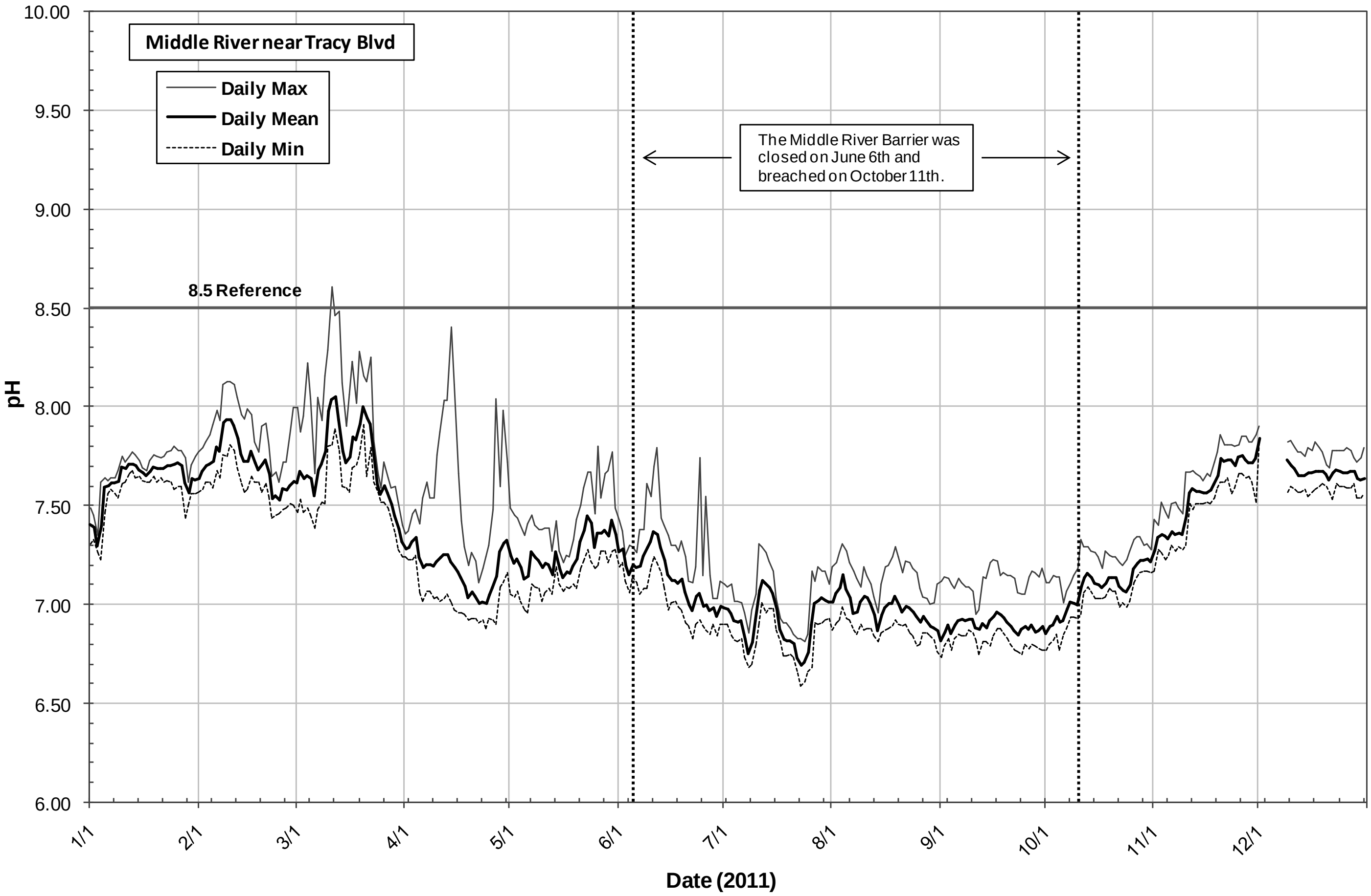


Figure 6-15: Daily pH time-series graphs for the Middle River stations



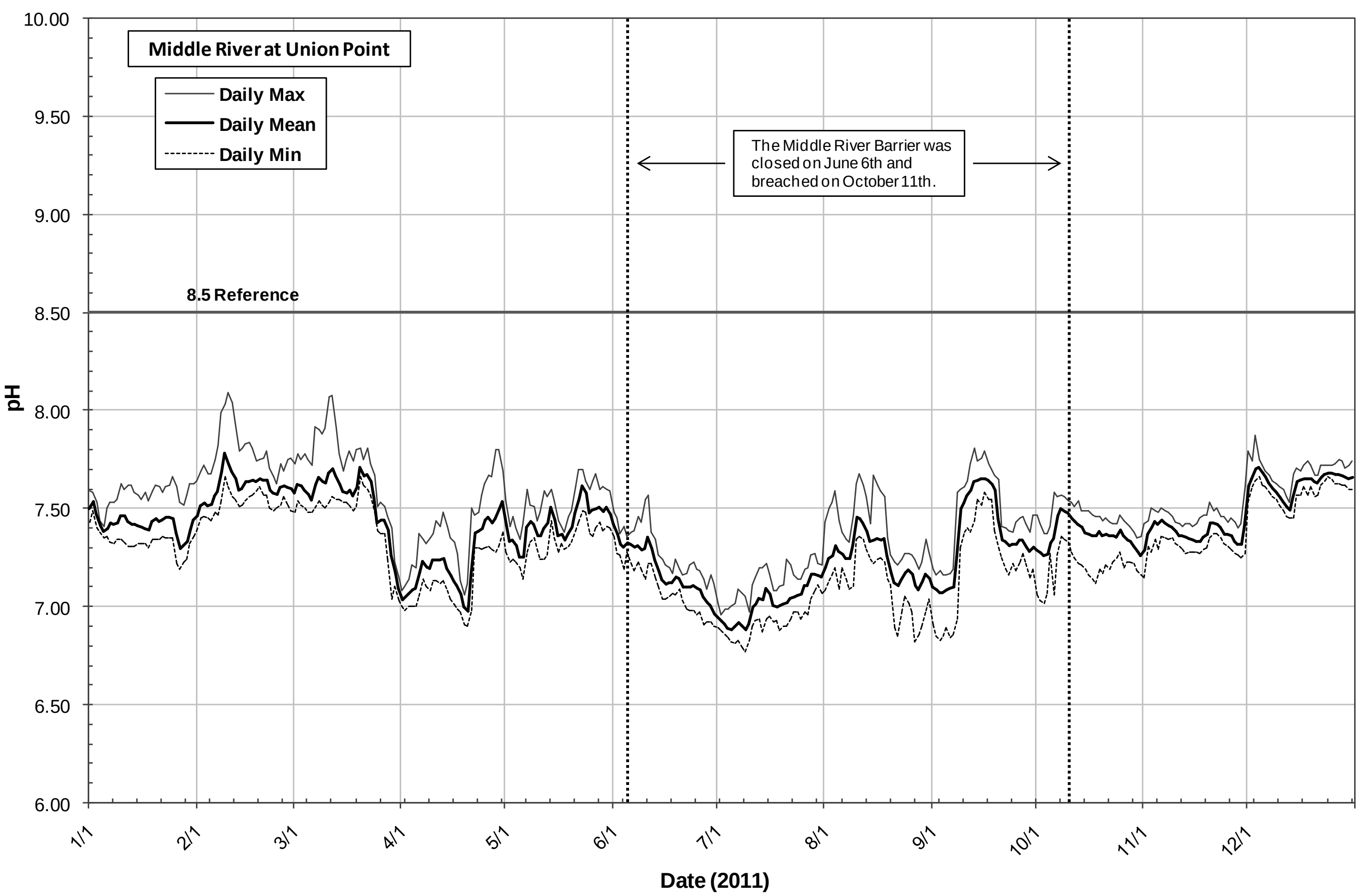
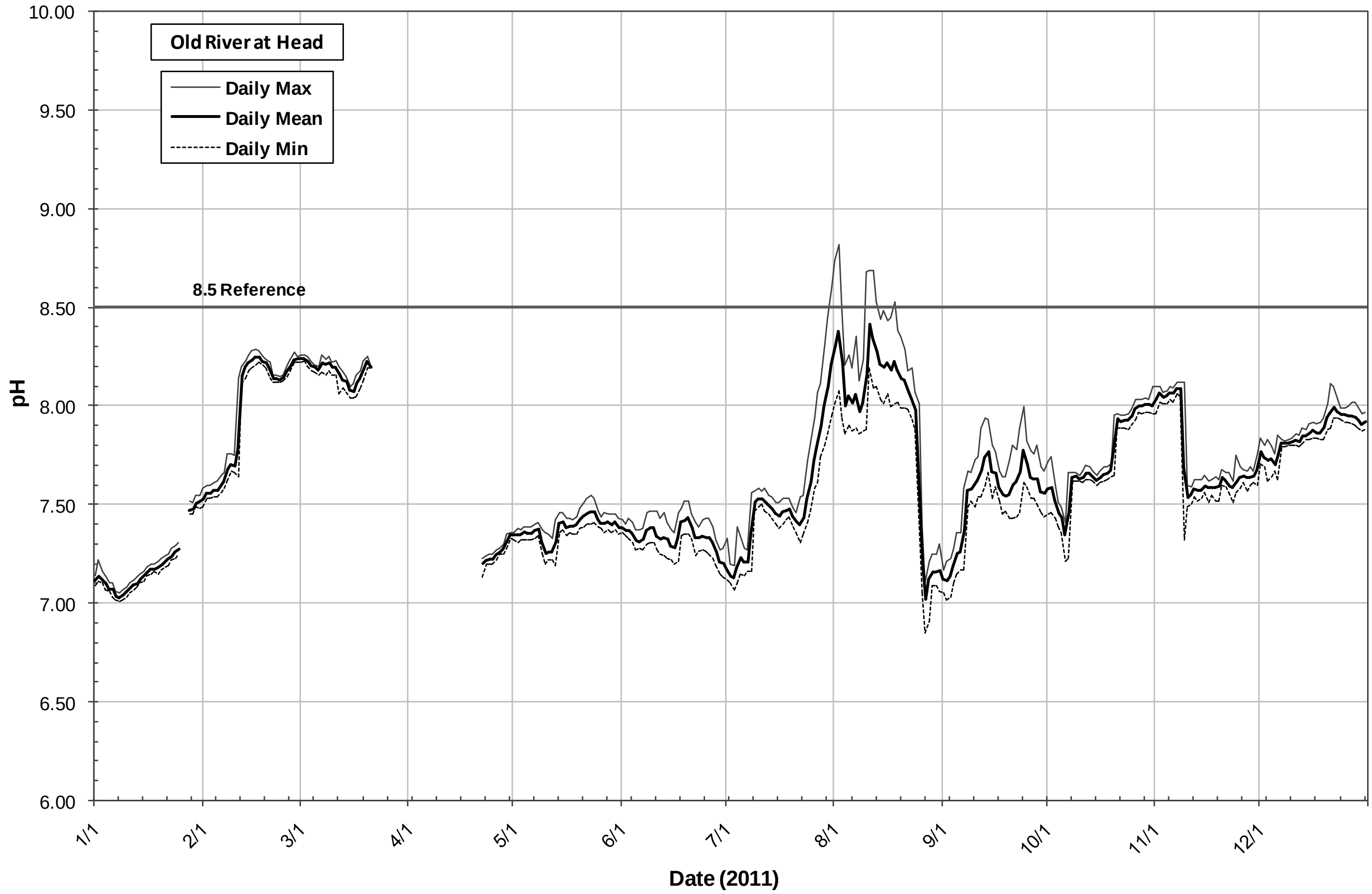


Figure 6-15: Daily pH time-series graphs for the Middle River stations



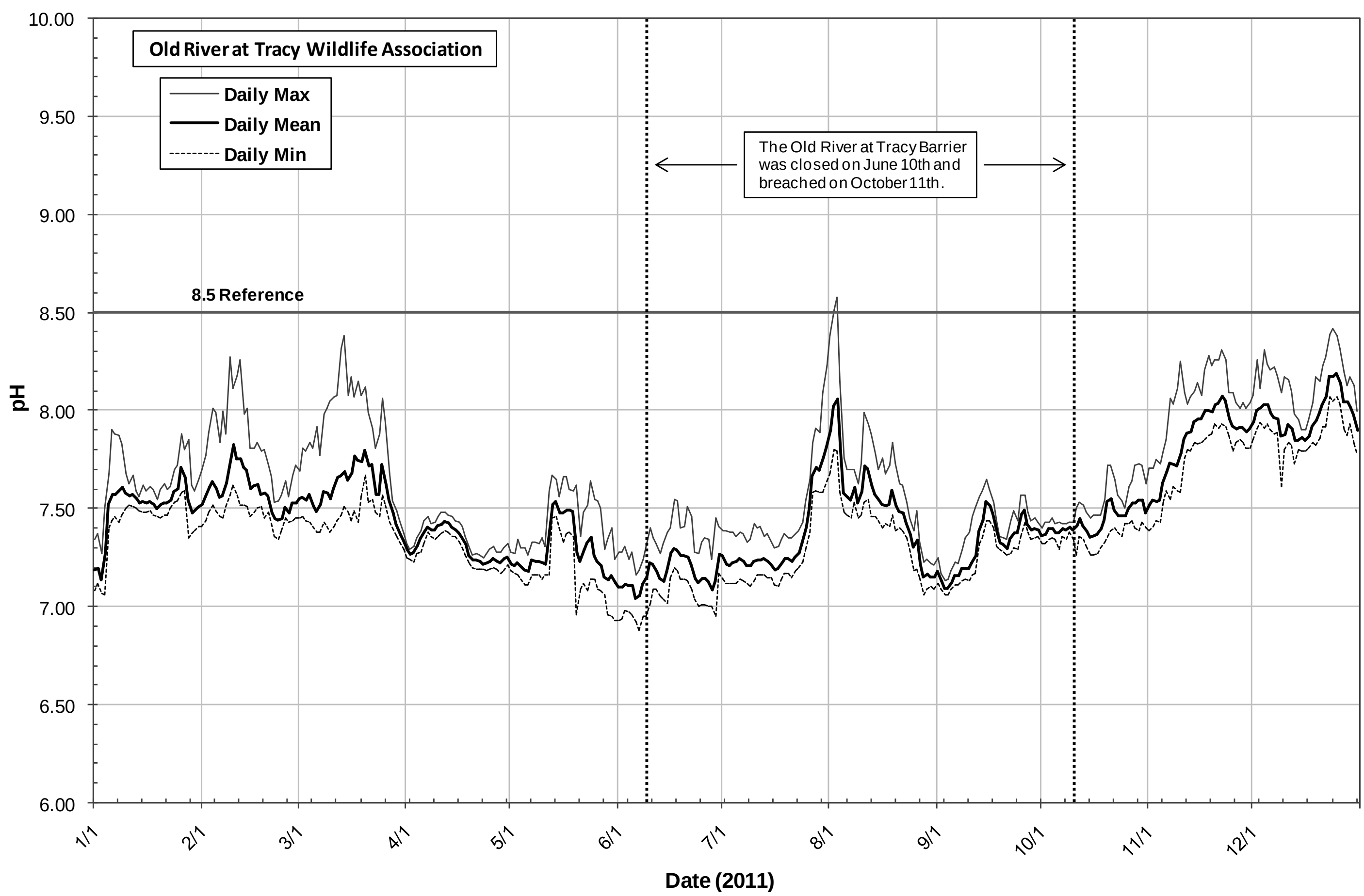
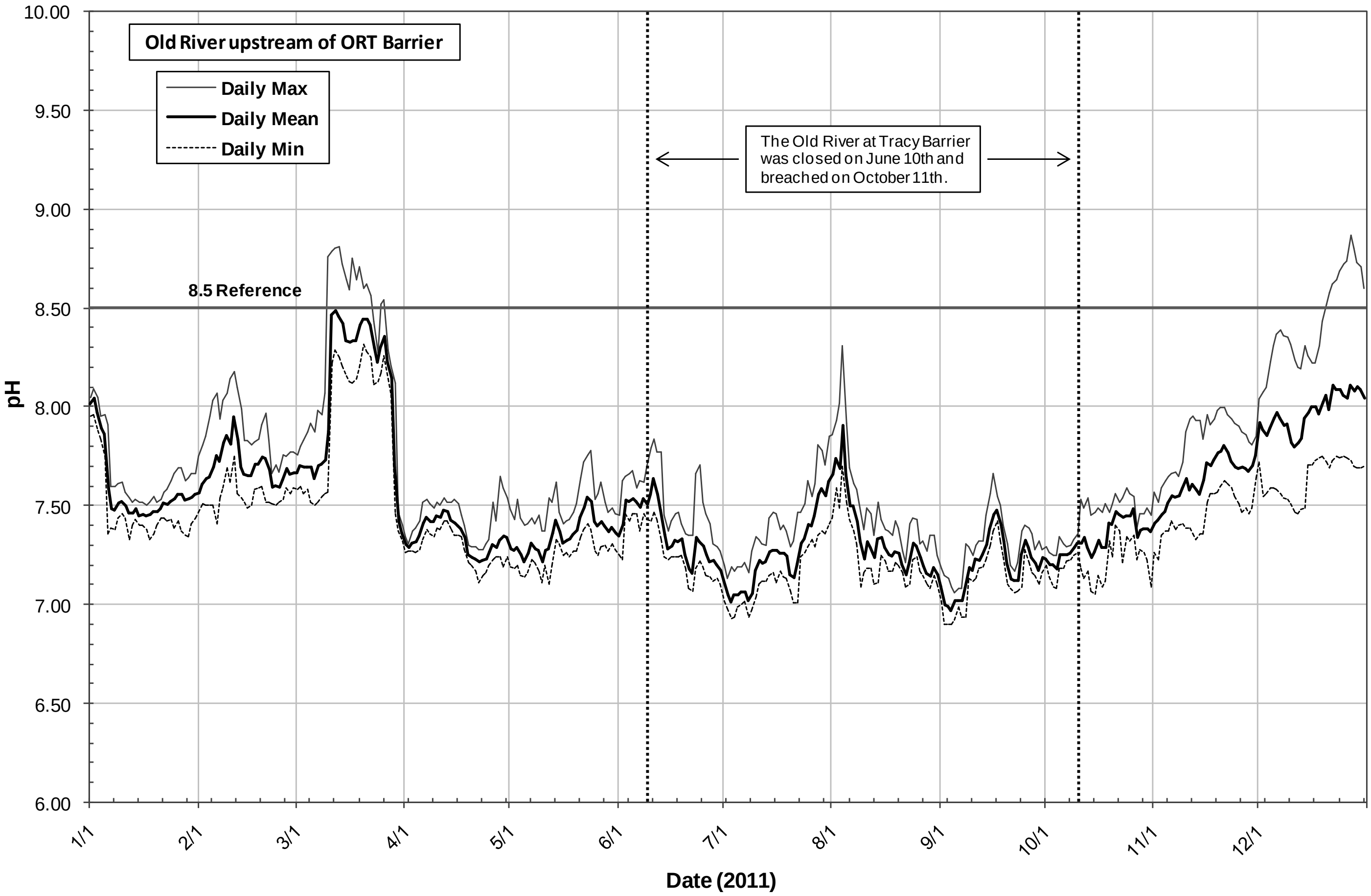


Figure 6-16: Daily pH time-series graphs for the Old River stations



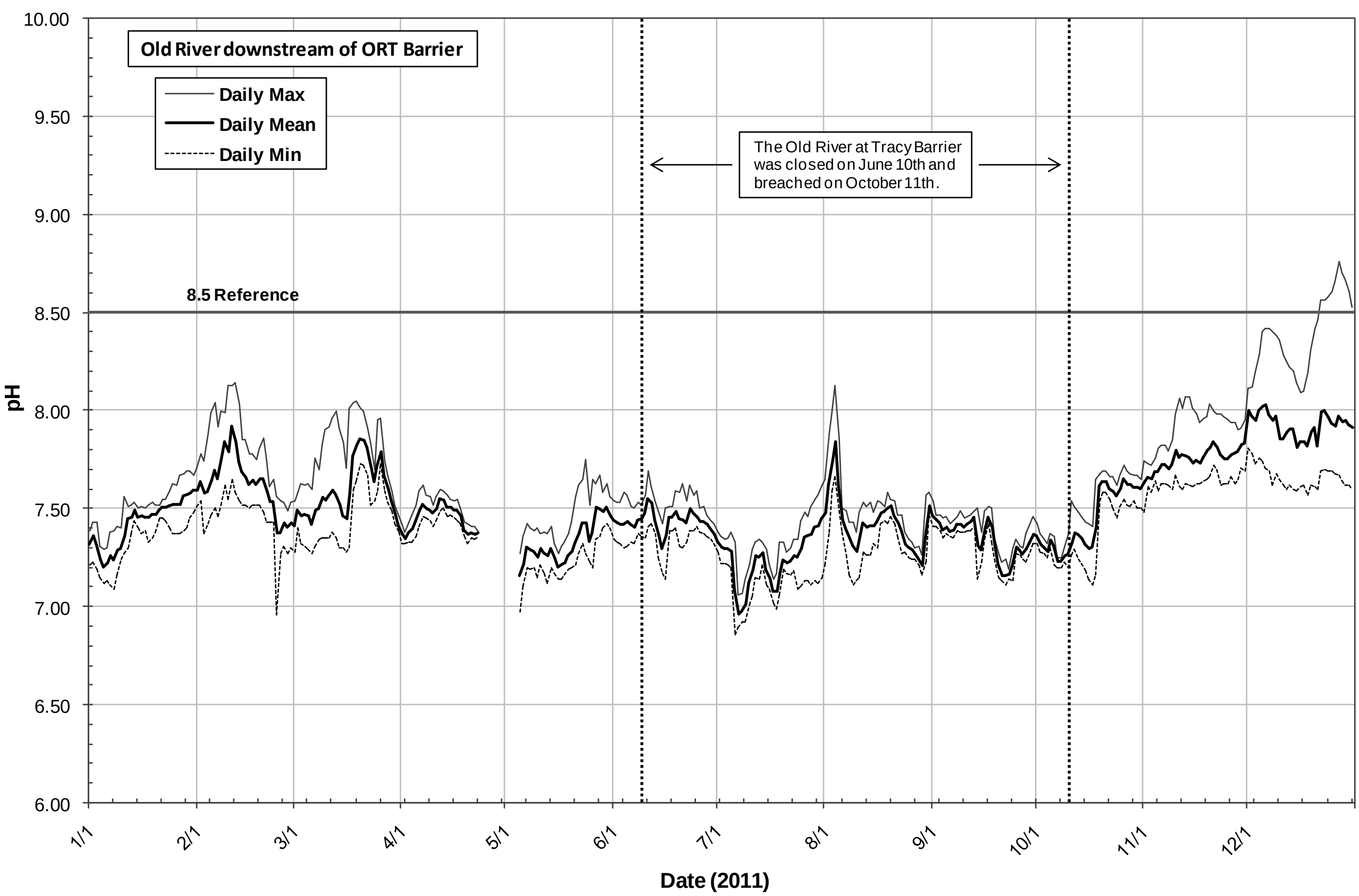
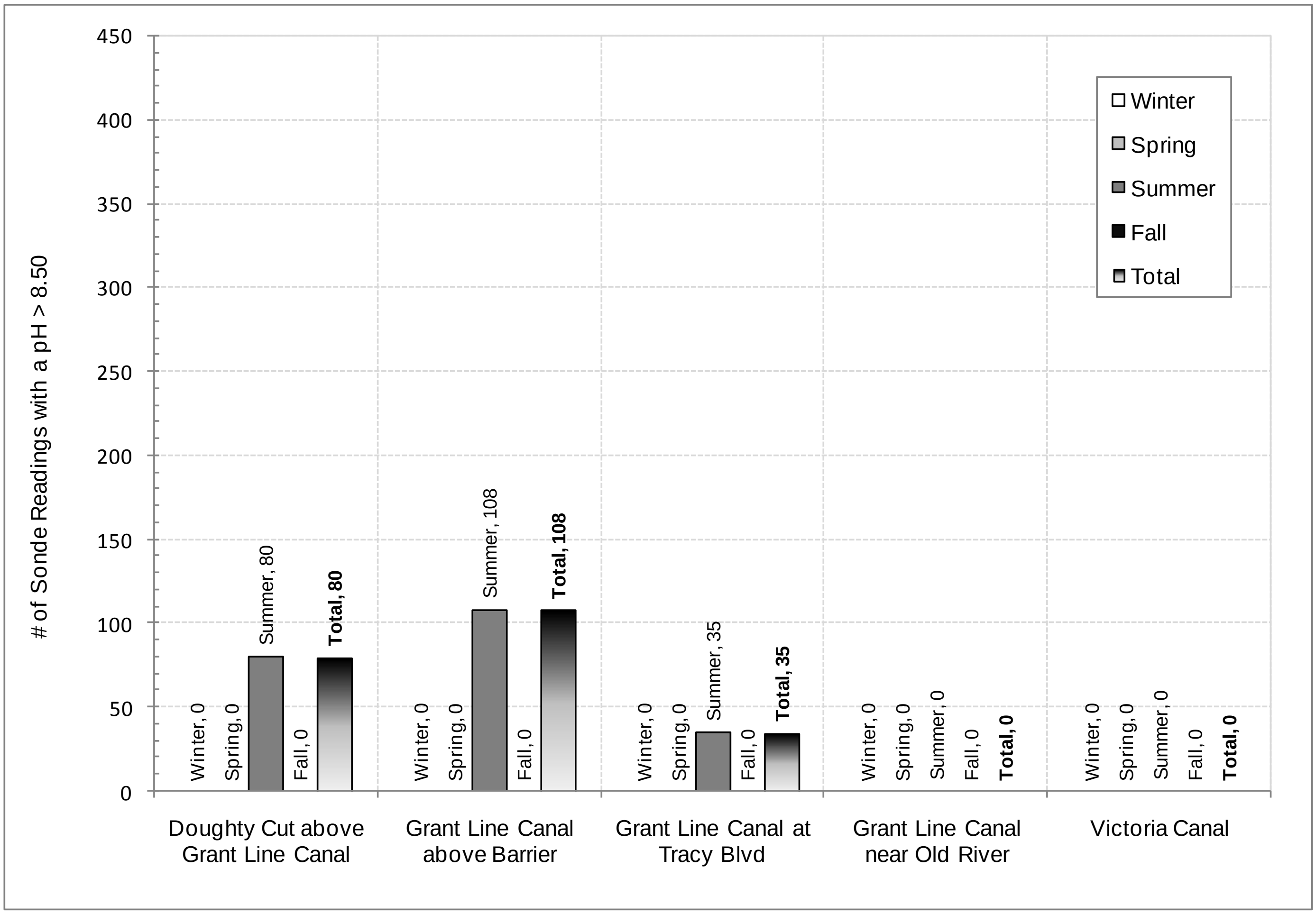


Figure 6-16: Daily pH time-series graphs for the Old River stations



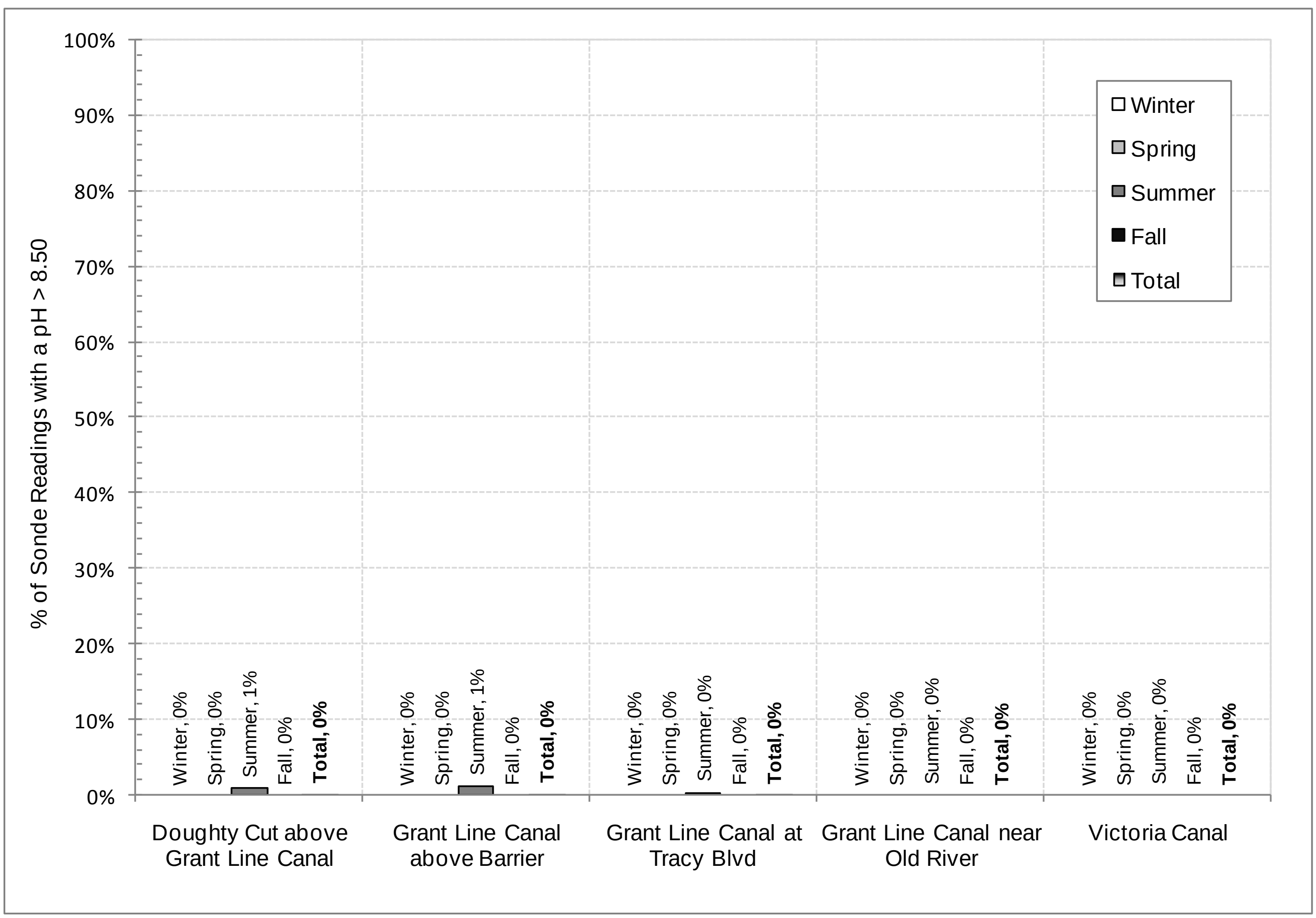
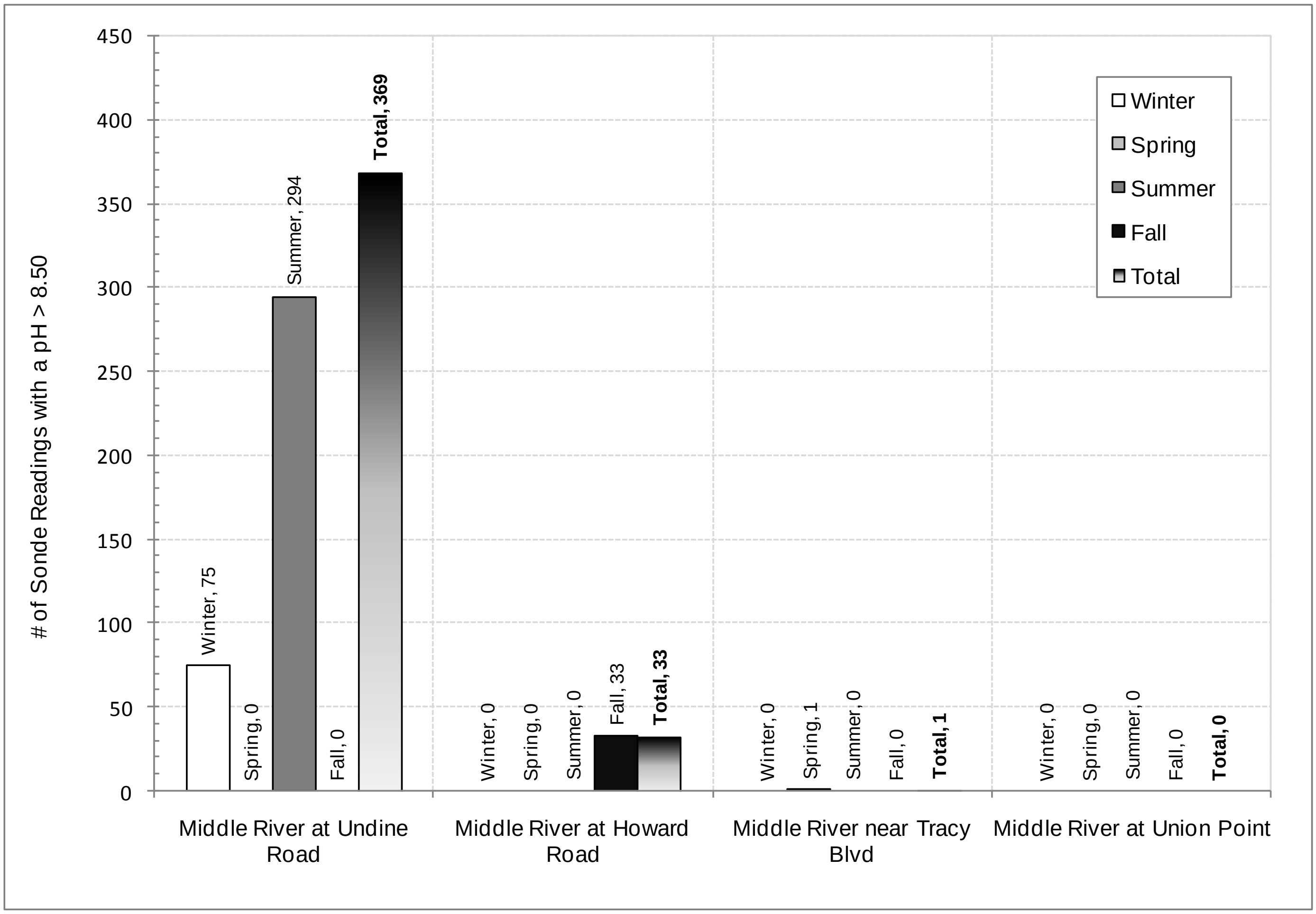


Figure 6-17: pH Standard Exceedences for the Grant Line and Victoria Canal stations



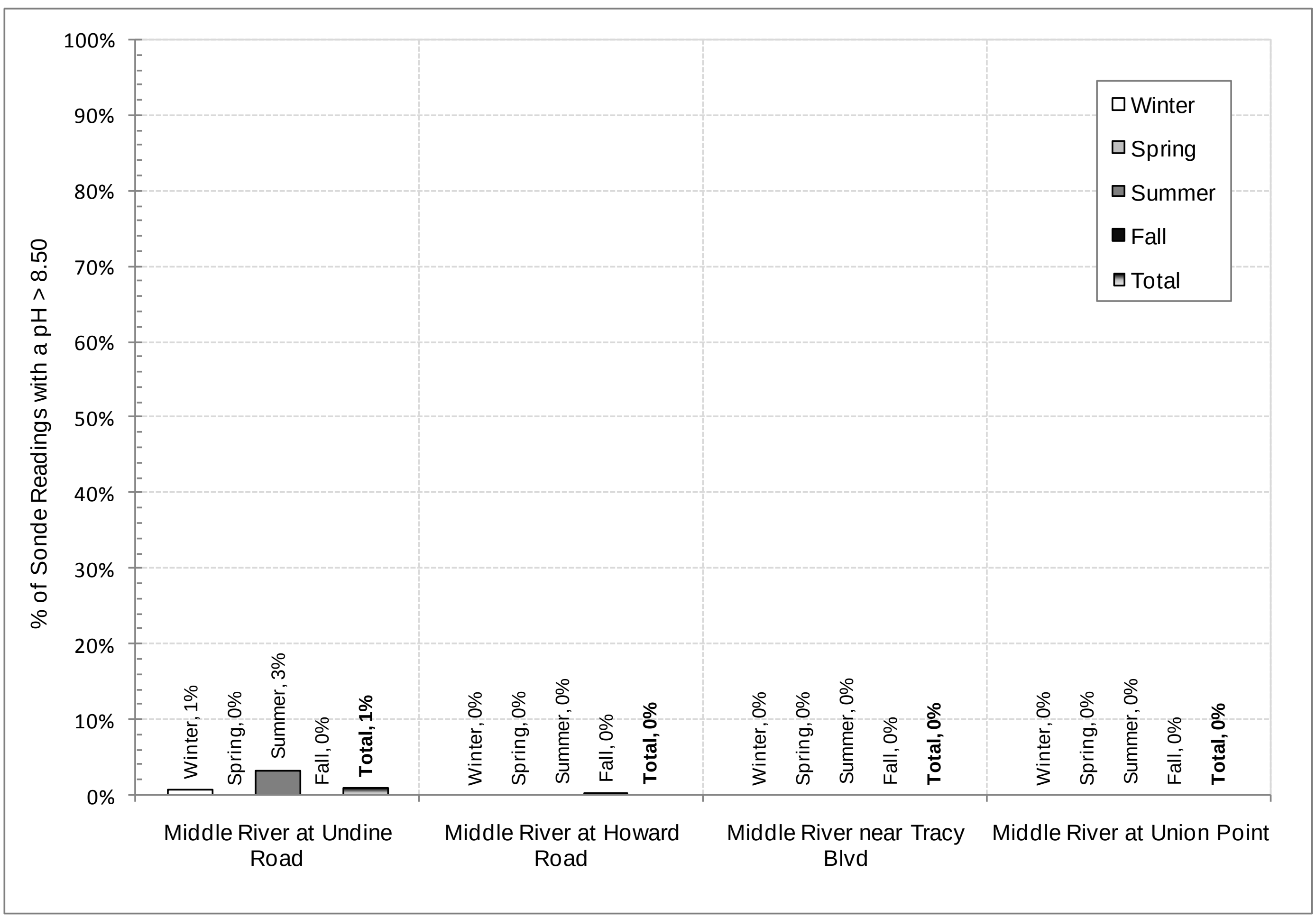
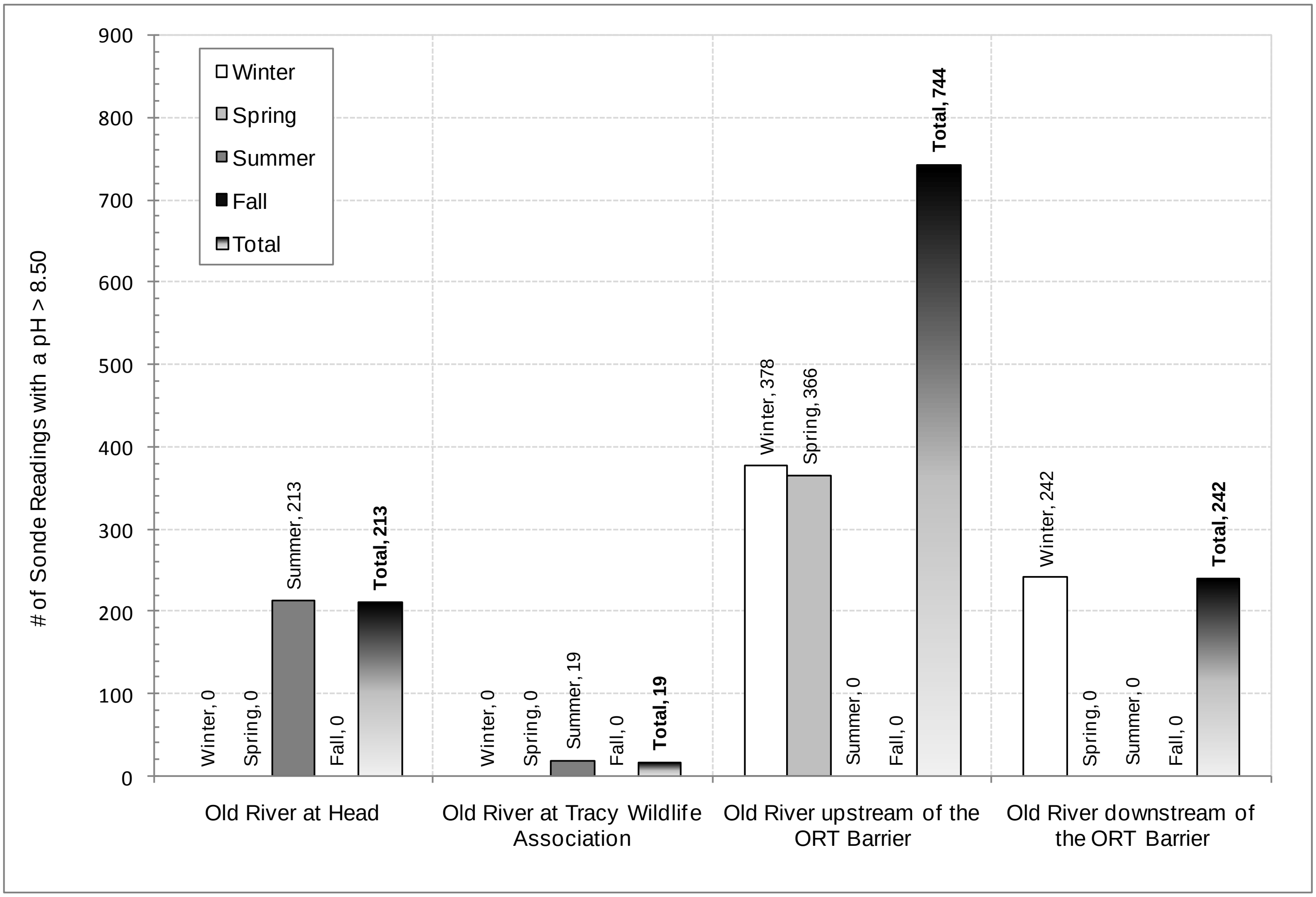


Figure 6-18: pH Standard Exceedences for the Middle River stations



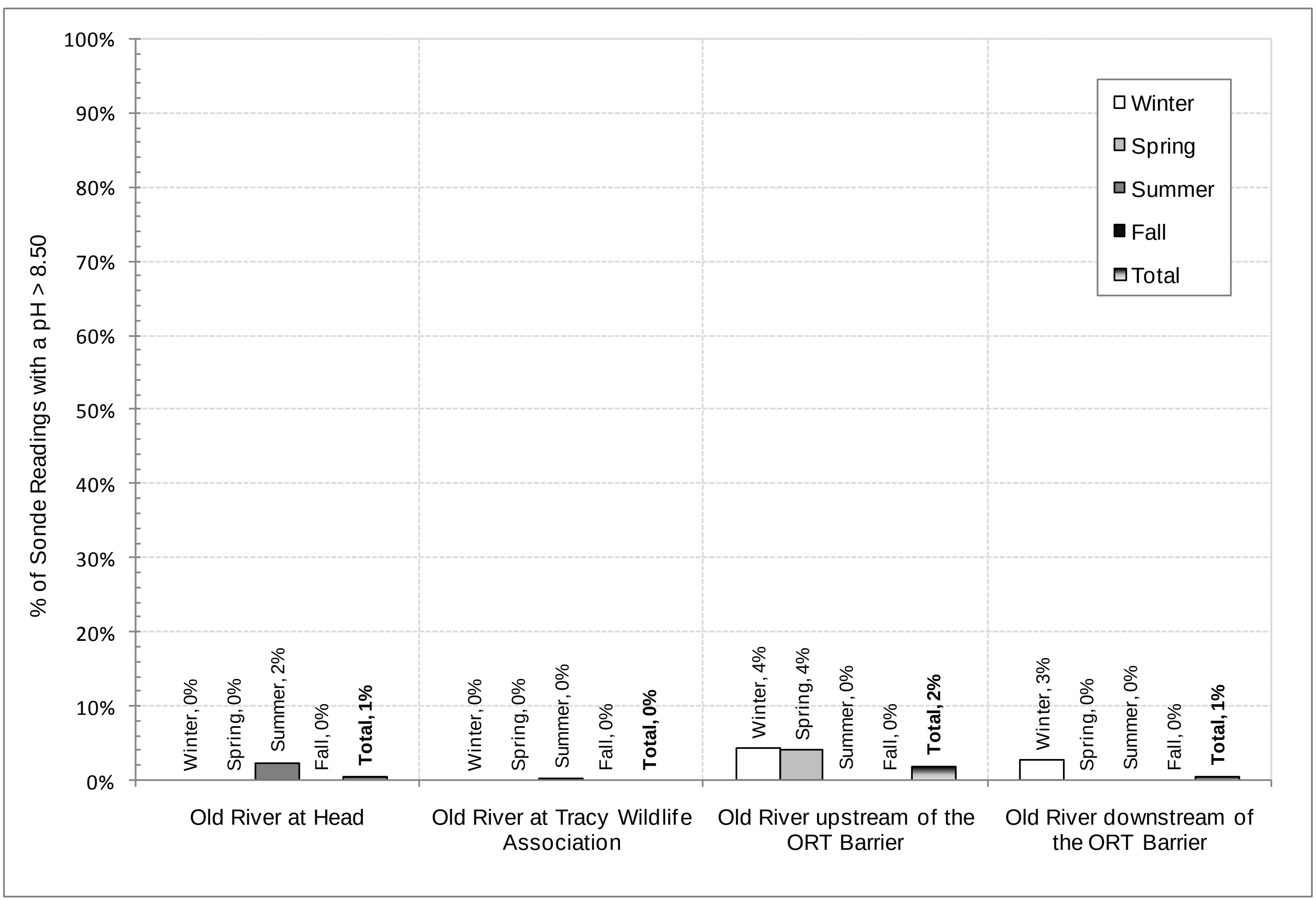


Figure 6-19: pH Standard Exceedences for the Old River stations

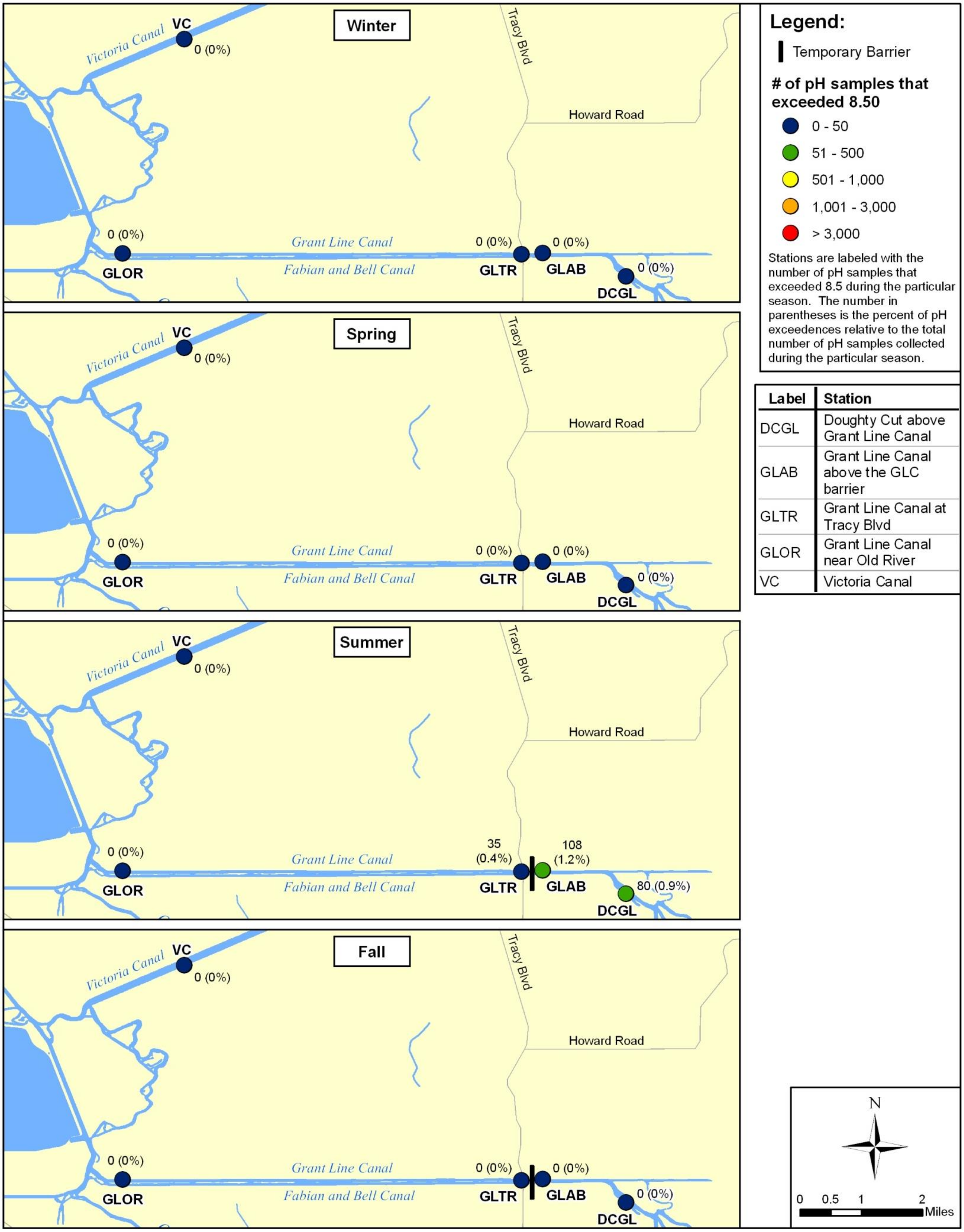


Figure 6-20: Map of pH Standard Exceedences for the Grant Line and Victoria Canal stations

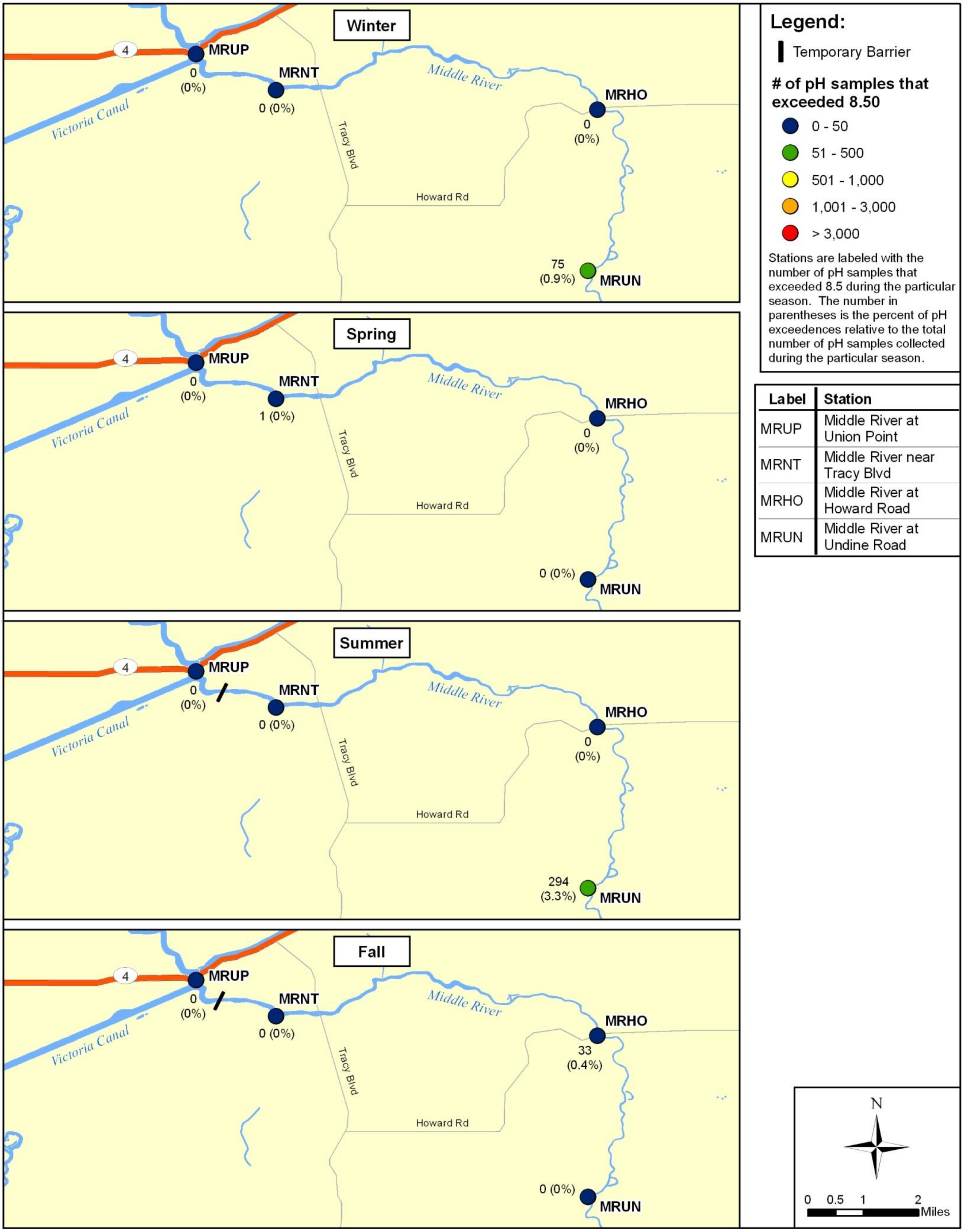


Figure 6-21: Map of pH Standard Exceedences for the Middle River stations

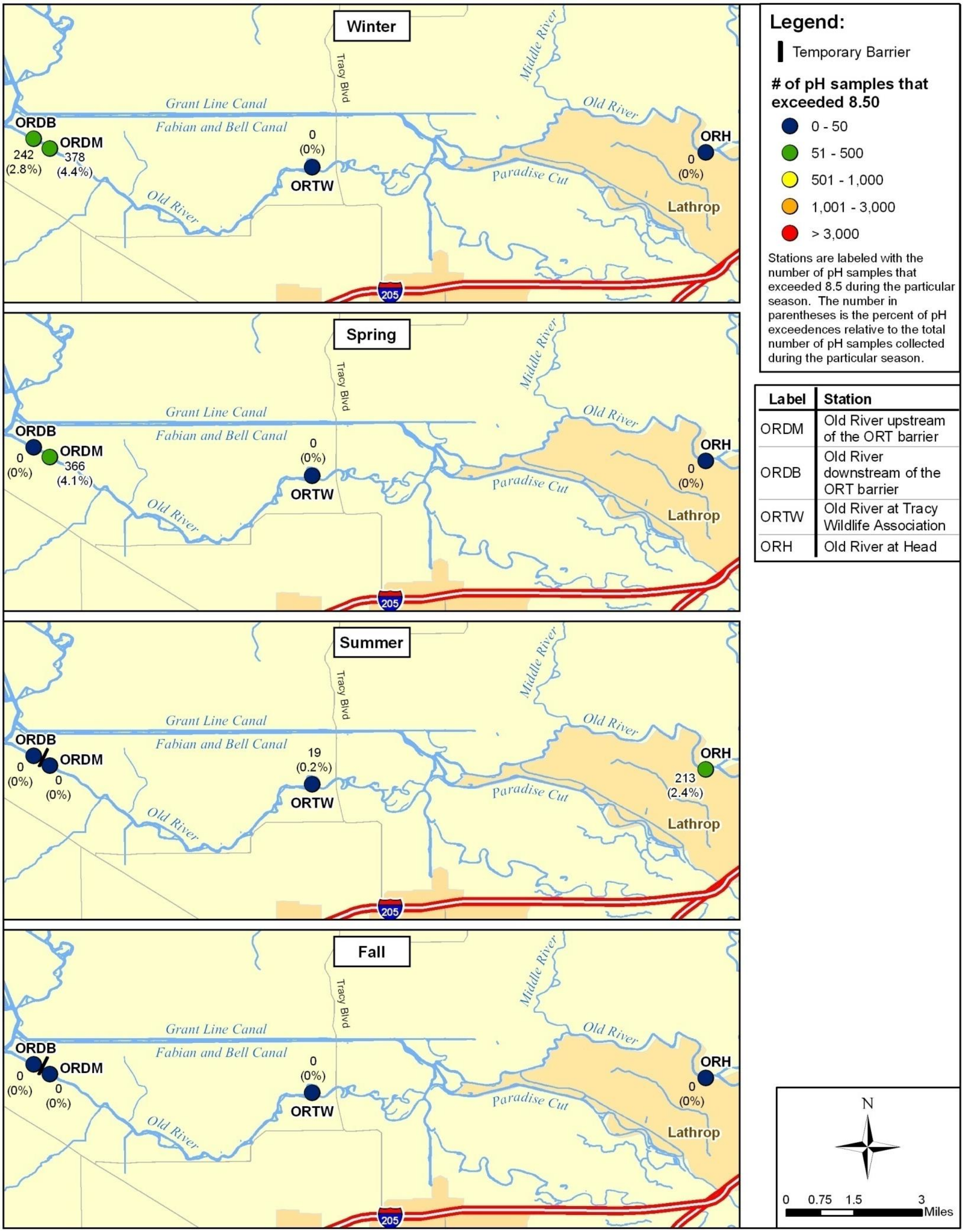


Figure 6-22: Map of pH Standard Exceedences for the Old River stations

Specific Conductance

Conductivity is a measure of the ability of an aqueous solution to carry an electrical current (APHA, 2005). Specific conductance values are temperature compensated to 25 ºC and can be used to estimate salinity and total dissolved solids (Wagner et al., 2006). Specific conductance is of vital importance in the South Delta because the water is used for irrigation. High amounts of dissolved salts in irrigation water can result in crop damage and reduced yield. Specific conductance data measured at various locations along a particular waterbody can be used to determine if a major input of water with a different conductivity enters the system between the locations; a significant difference at one or more locations could indicate that the water nearby these sites comes from a different source composition.

Tables 6-3, 6-4, 6-5, and 6-6 provide monthly summary statistics for the Grant Line Canal, Victoria Canal, Middle River, and Old River stations, respectively. In addition, Figures 6-23, 6-24, and 6-25 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively. Generally, during the first half of the 2011 monitoring period the specific conductance values were slightly higher at most stations during January, February, and March, and there was a slight decrease in mid-April to mid-July. This decrease was most likely a result of heavy spring rains, greater spring and early summer snowmelt, and higher flows in the lower San Joaquin River in April and May due to the Vernalis Adaptive Management Plan[8]. At most of the stations, there were two obvious increases in specific conductance values during the beginning of August and mid-September (Figures 6-23 to 6-25). There was also a significant increase in specific conductance values at most of the stations starting at the beginning of November 2011 and continuing through the end of the year, which was probably due to the very dry start of the 2011-2012 winter.

The State Water Resources Control Board has specific conductivity objectives for three sites in the South Delta; San Joaquin River at Brandt Bridge, Old River near Middle River, and Old River at Tracy Road Bridge. The thirty-day running average for these sites should not exceed 700 µS/cm from April 1st-August 31st and 1,000 µS/cm from September 1st-March 31st.

April through August 2011 – Agricultural Season

The maximum recorded specific conductance during this time period was 731 µS/cm on August 11th at Middle River at Howard Road, and the minimum was 108 µS/cm on July 2nd at Middle River at Undine Road (Tables 6-3 to 6-6). Monthly mean values for this time period ranged from 141 µS/cm in April at Old River at Head to 354 µS/cm in August at both the Old River upstream and downstream of the ORT barrier stations. None of the thirteen continuous monitoring sites had a month where specific conductance averaged 700 µS/cm or higher during this time period.

January-March 2011 and September-December 2011

The maximum recorded specific conductance during this time period was 1,424 µS/cm on December 13th at Middle River at Undine Road, and the minimum was 153 µS/cm on January 2nd at Doughty Cut above Grant Line Canal (Tables 6-3 to 6-6). Monthly mean values for this time period ranged from 216 µS/cm at Victoria Canal to 919 µS/cm at Old River at Tracy Wildlife Association. None of the thirteen continuous monitoring sites had a month where specific conductance averaged 1,000 µS/cm or higher during this time period.

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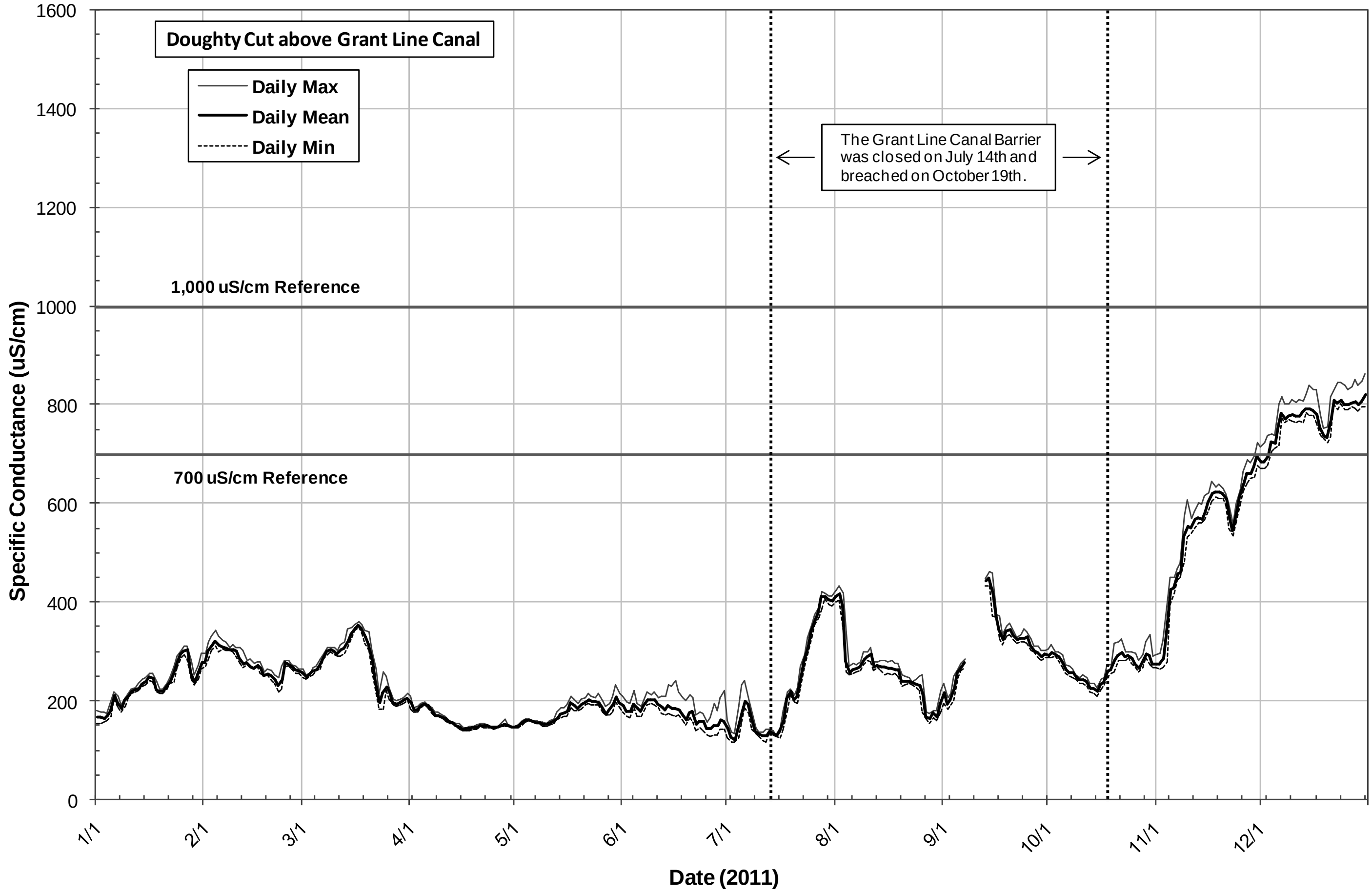
[8] The Vernalis Adaptive Management Plan is a long-term program designed to protect migrating juvenile Chinook salmon in the South Delta. The plan includes increasing the flow in the lower San Joaquin River from April through May by releasing more water from upstream reservoirs.



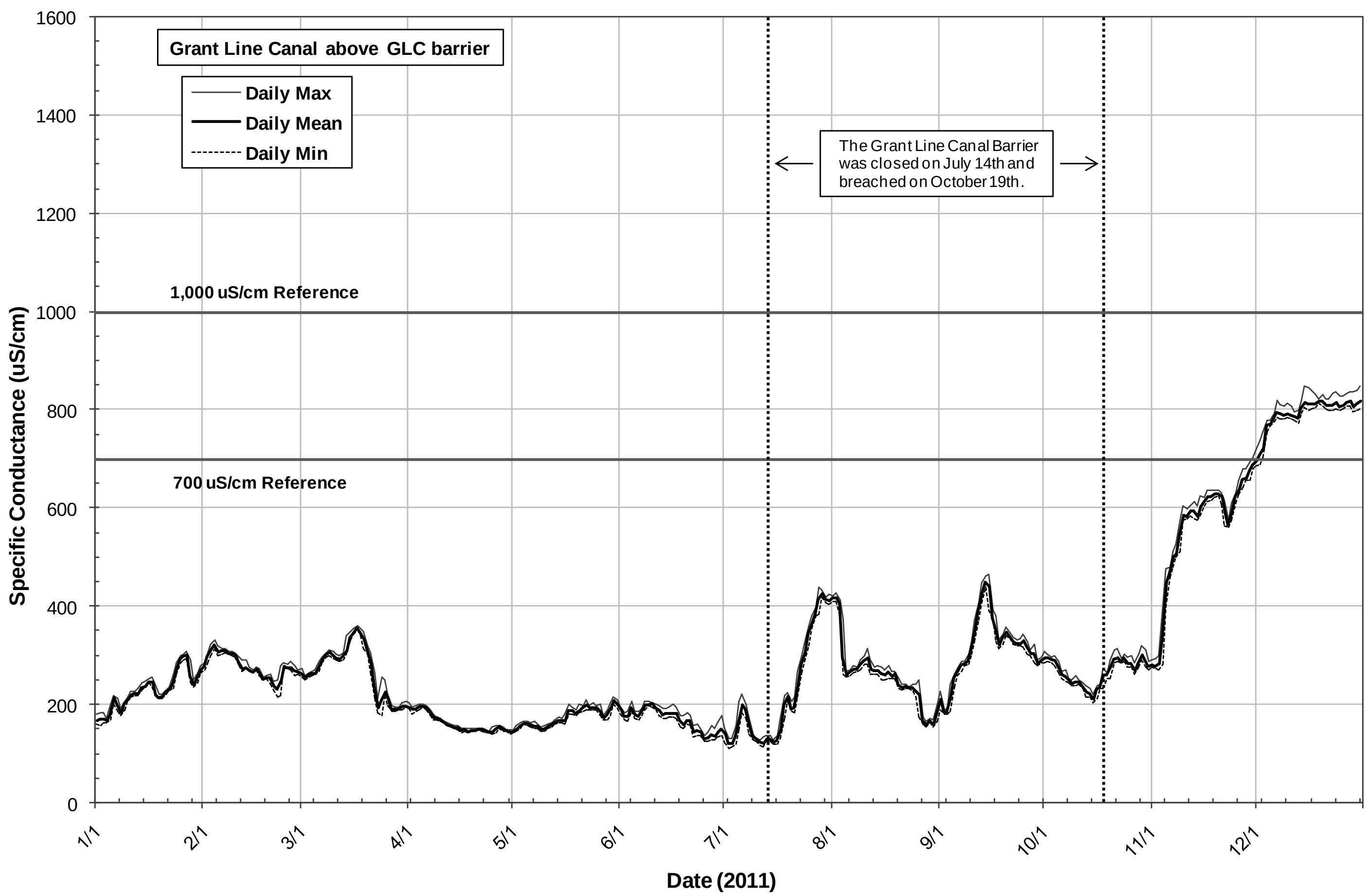
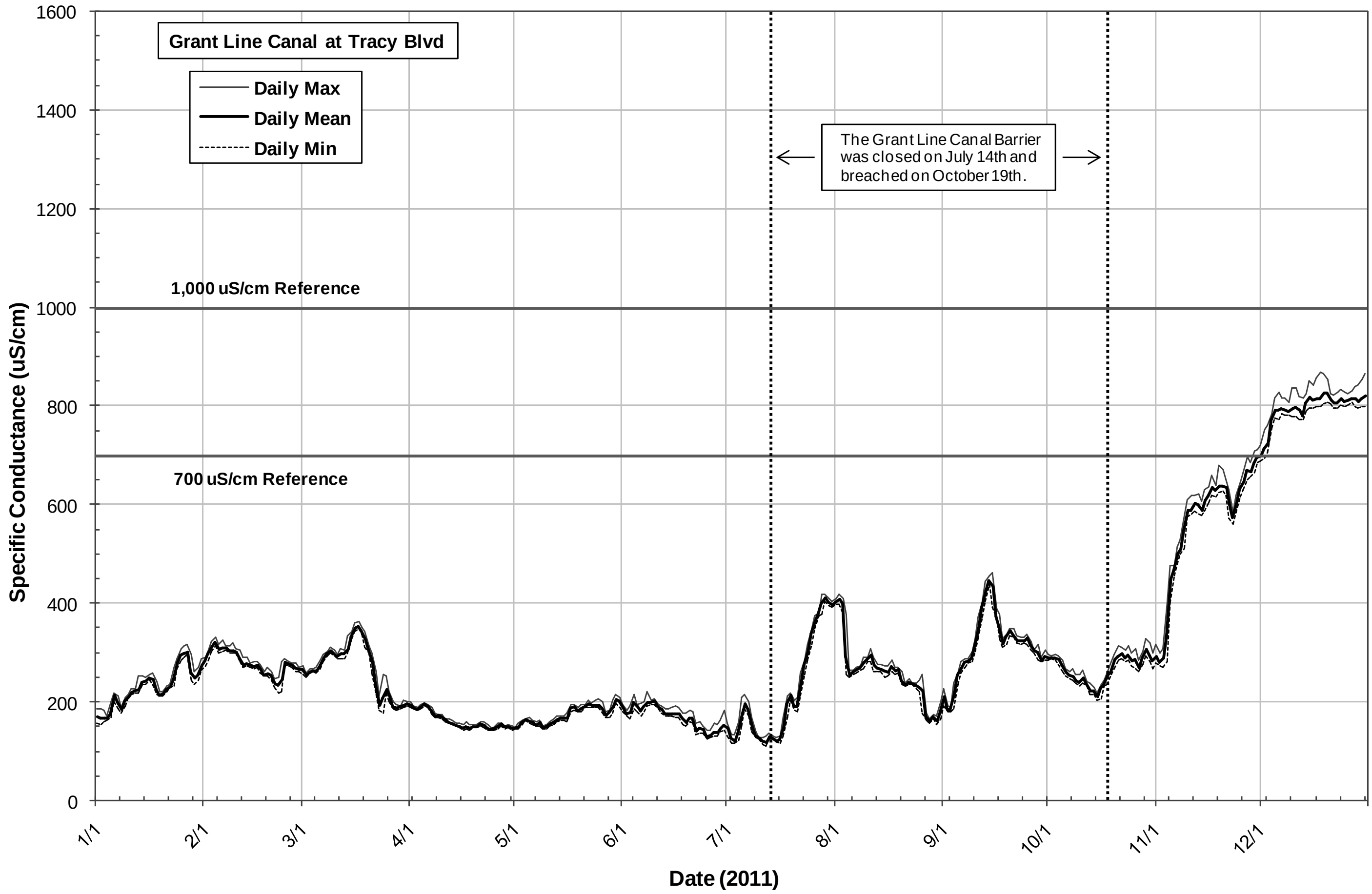


Figure 6-23: Daily Specific Conductance time-series graphs for the Grant Line and Victoria Canal stations



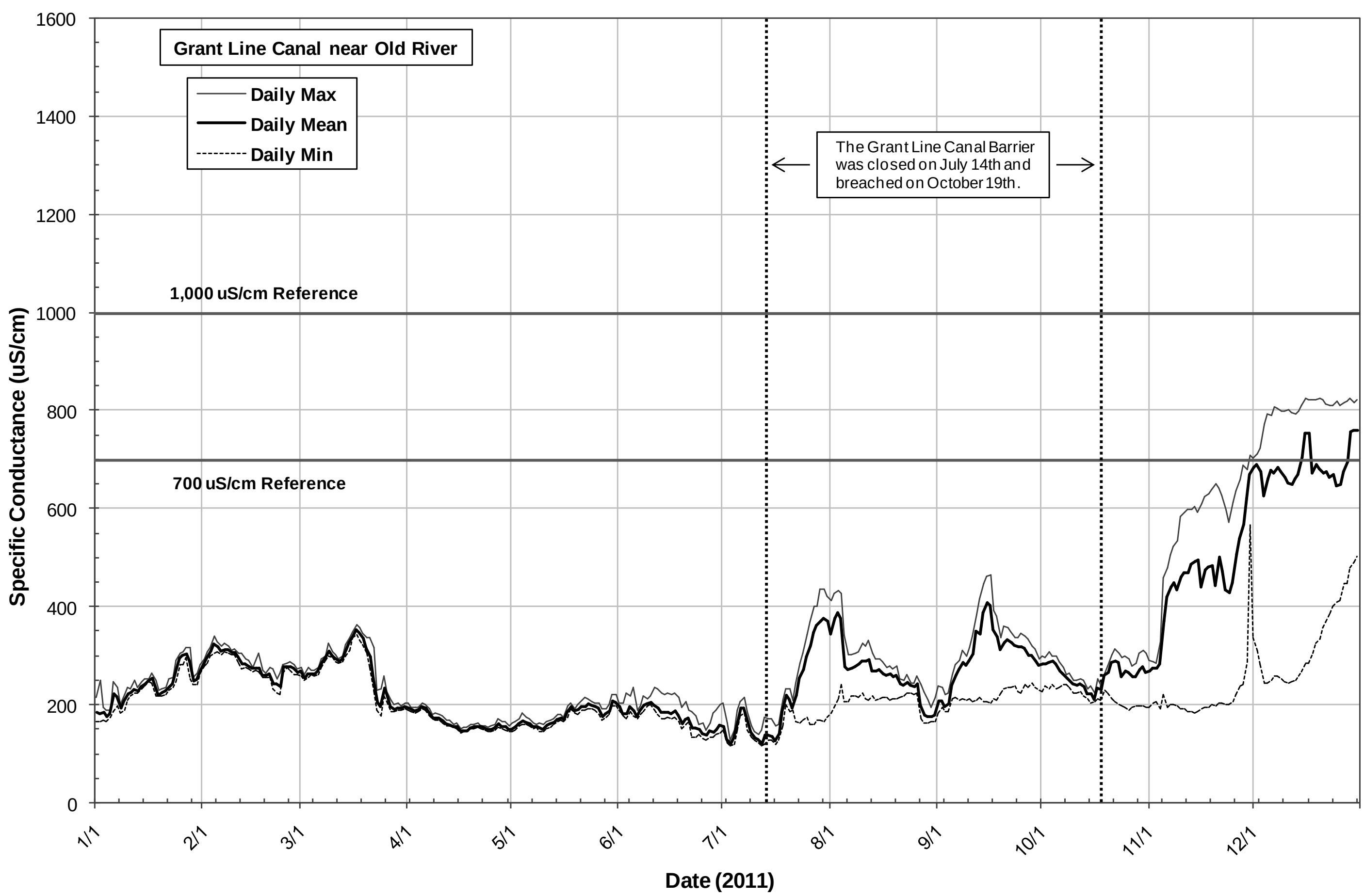


Figure 6-23: Daily Specific Conductance time-series graphs for the Grant Line and Victoria Canal stations

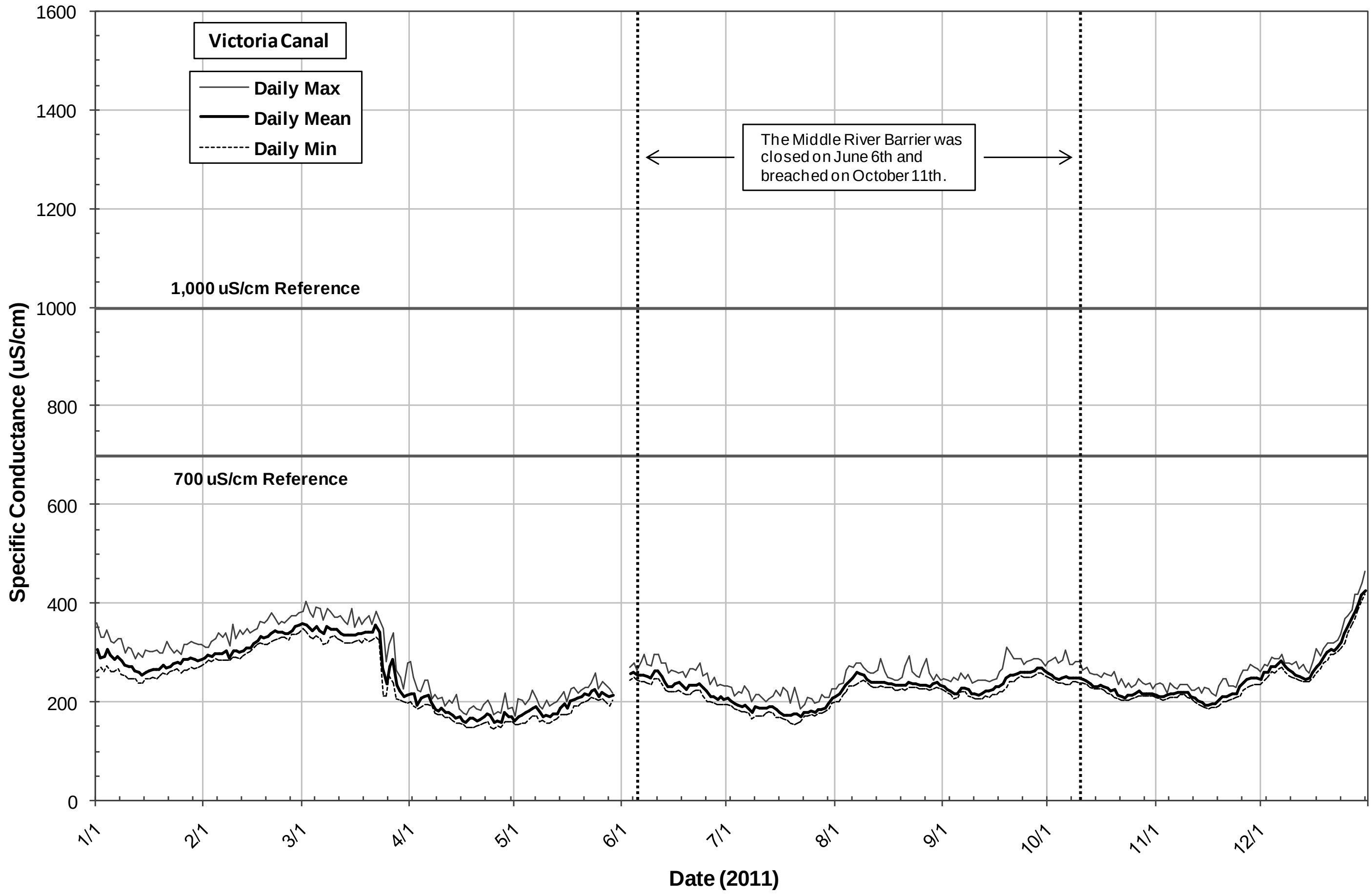
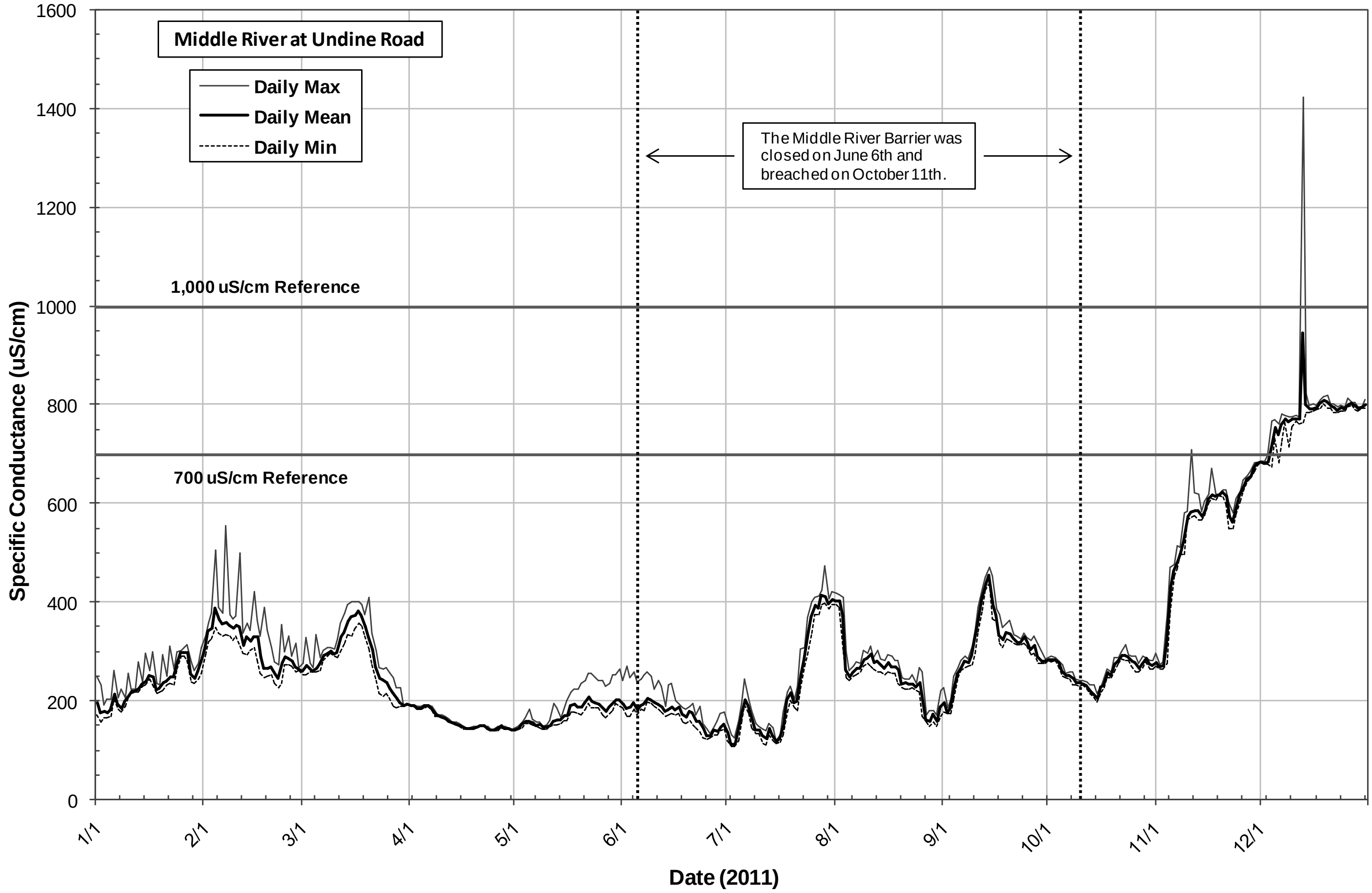


Figure 6-23: Daily Specific Conductance time-series graphs for the Grant Line and Victoria Canal stations



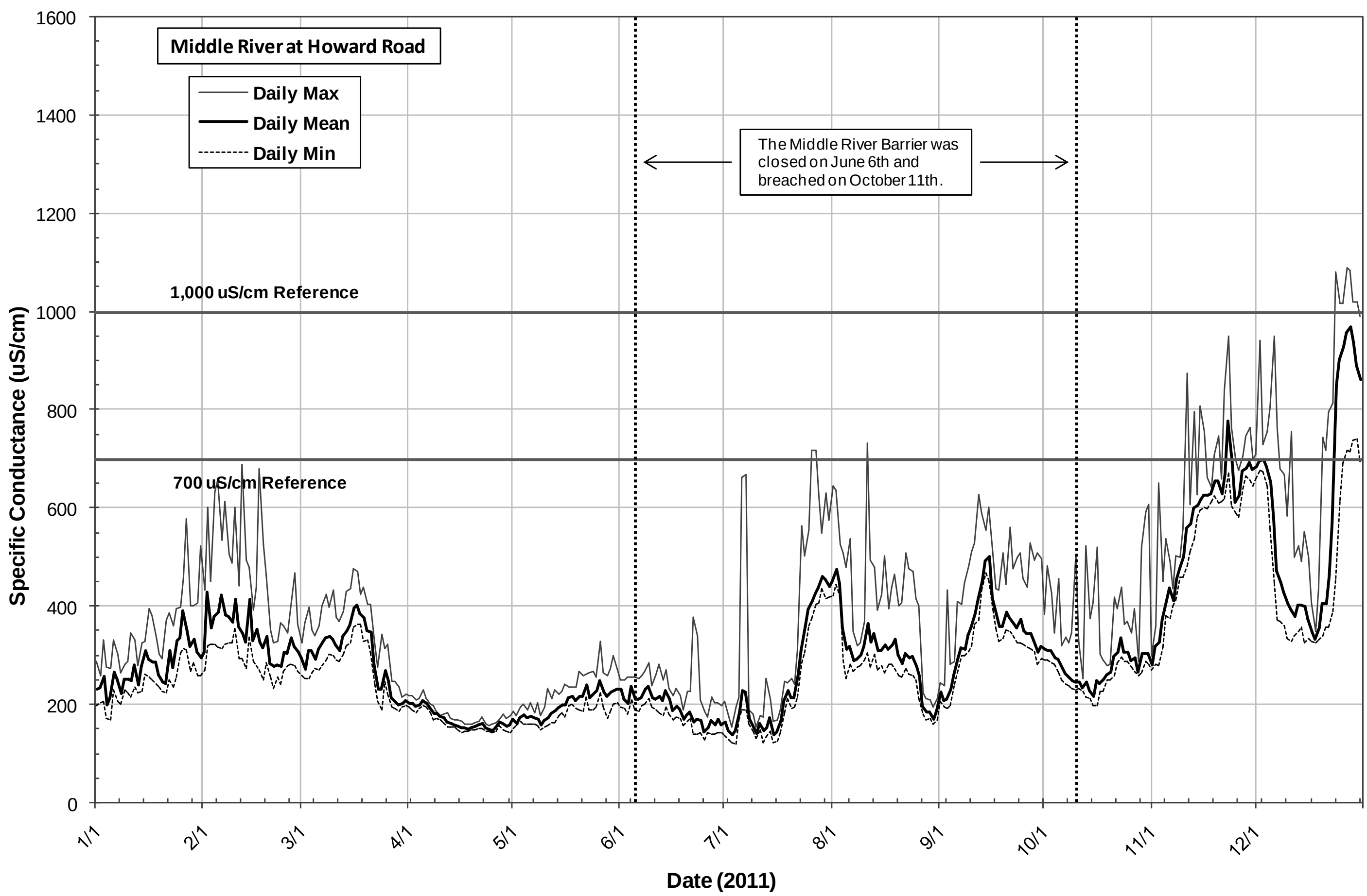
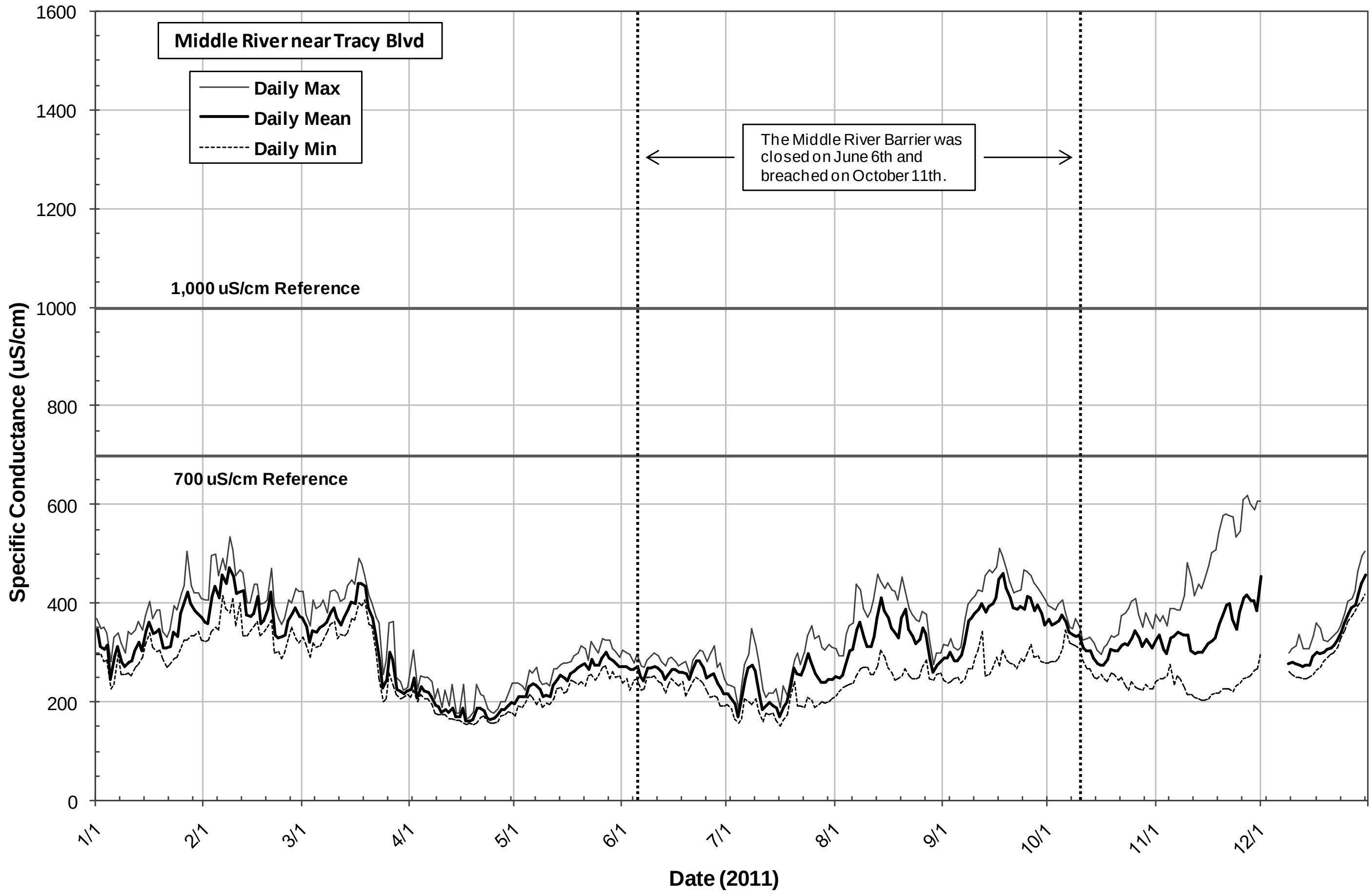


Figure 6-24: Daily Specific Conductance time-series graphs for the Middle River stations



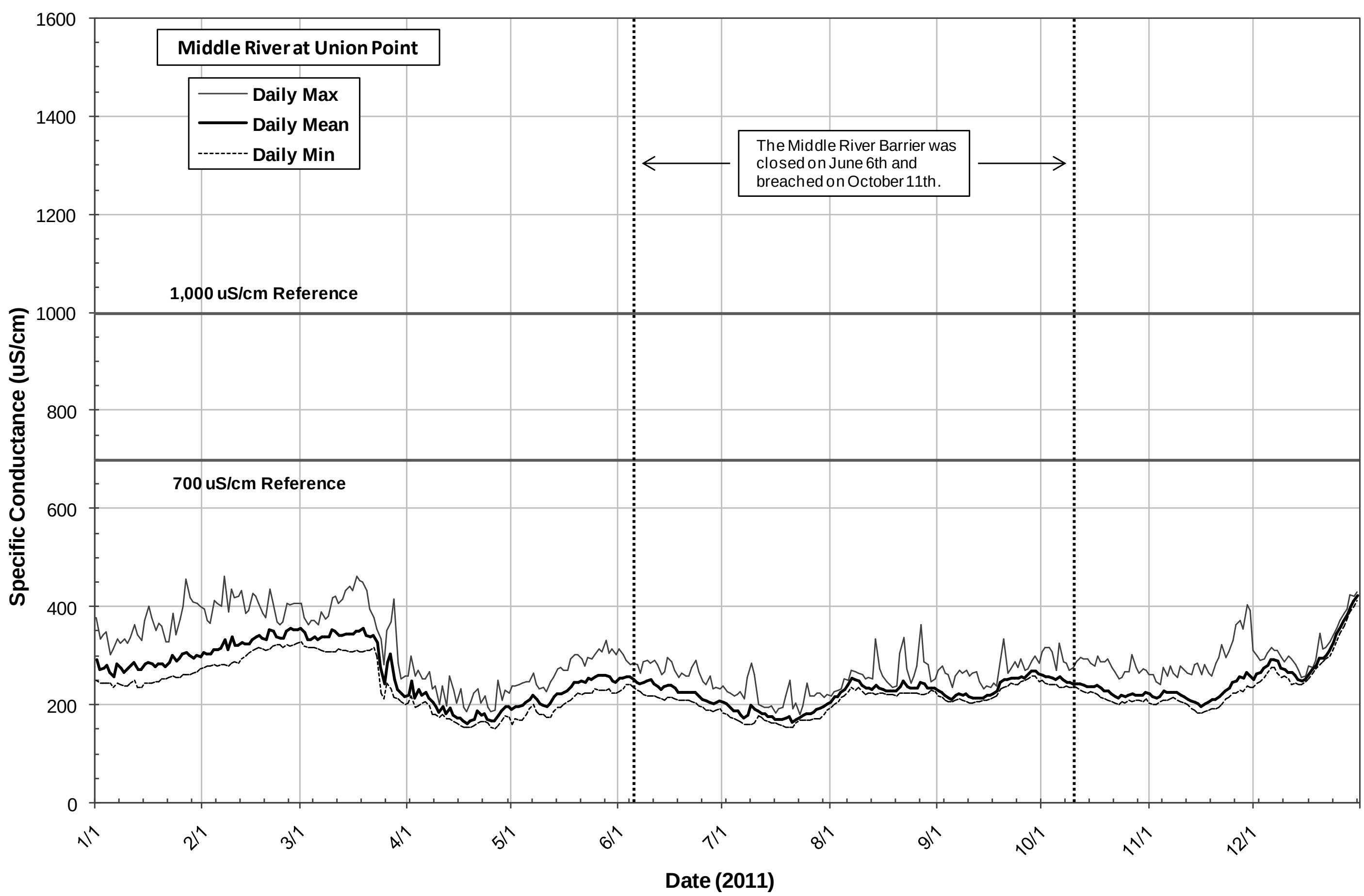
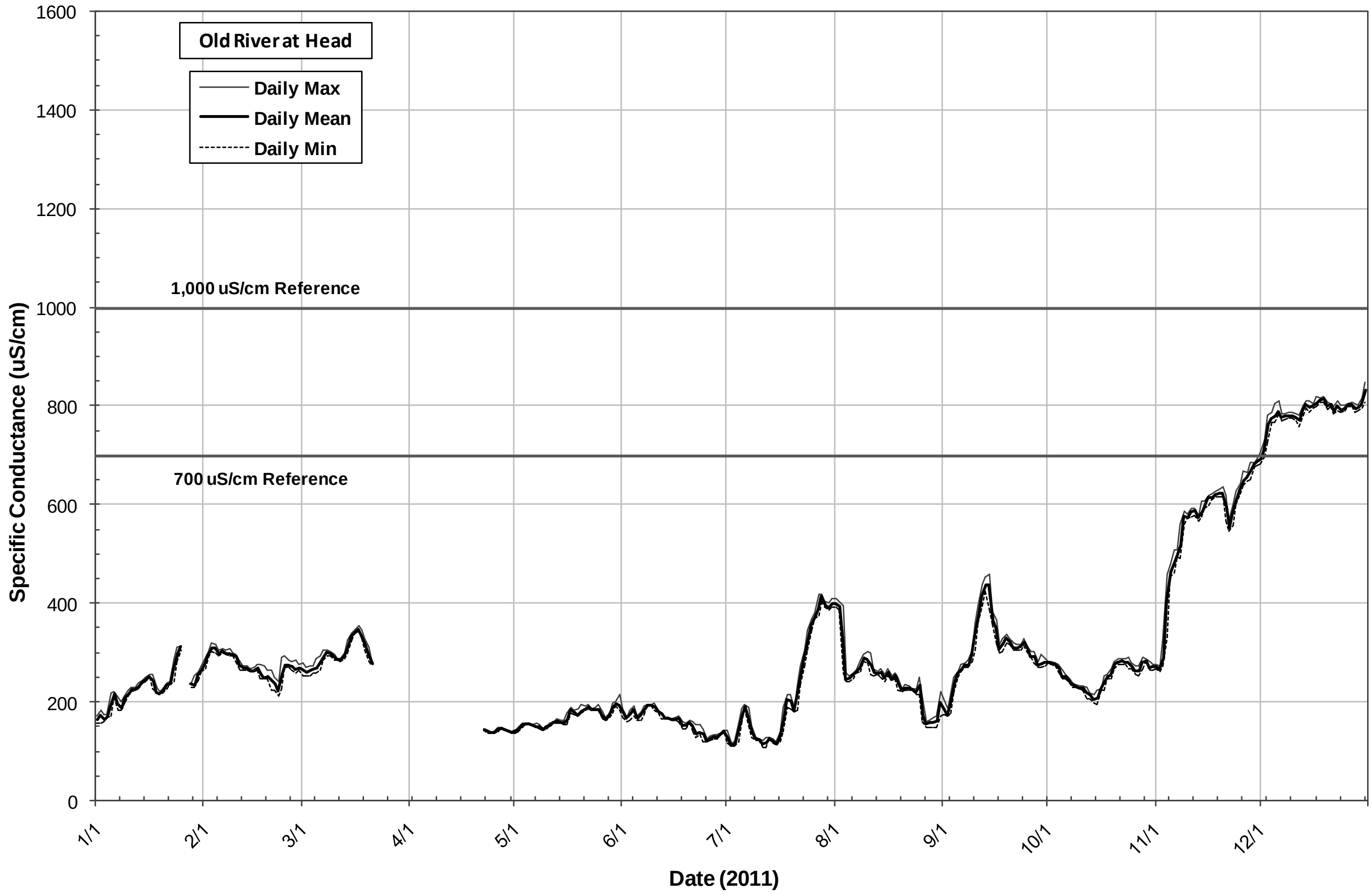


Figure 6-24: Daily Specific Conductance time-series graphs for the Middle River stations



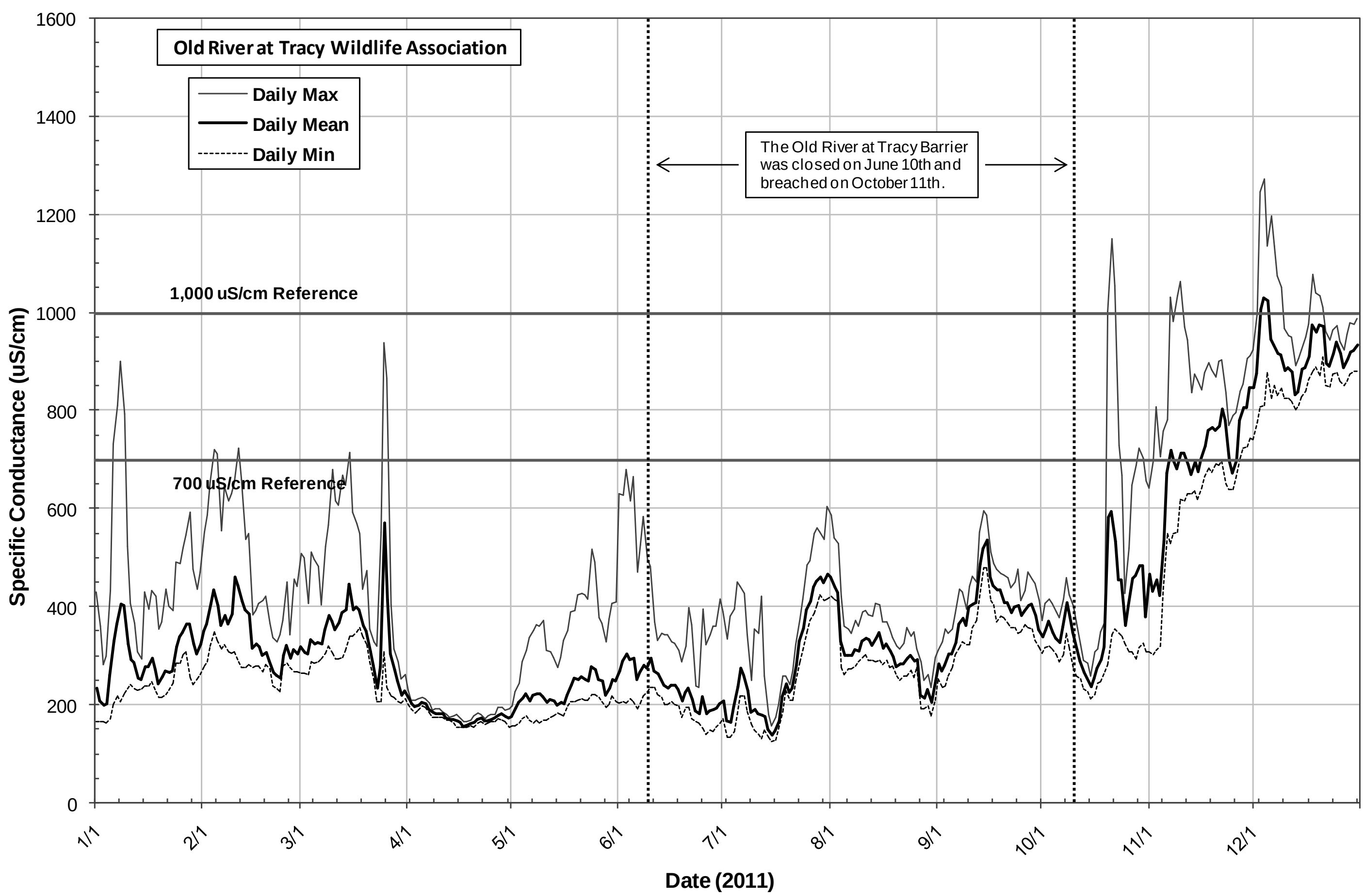
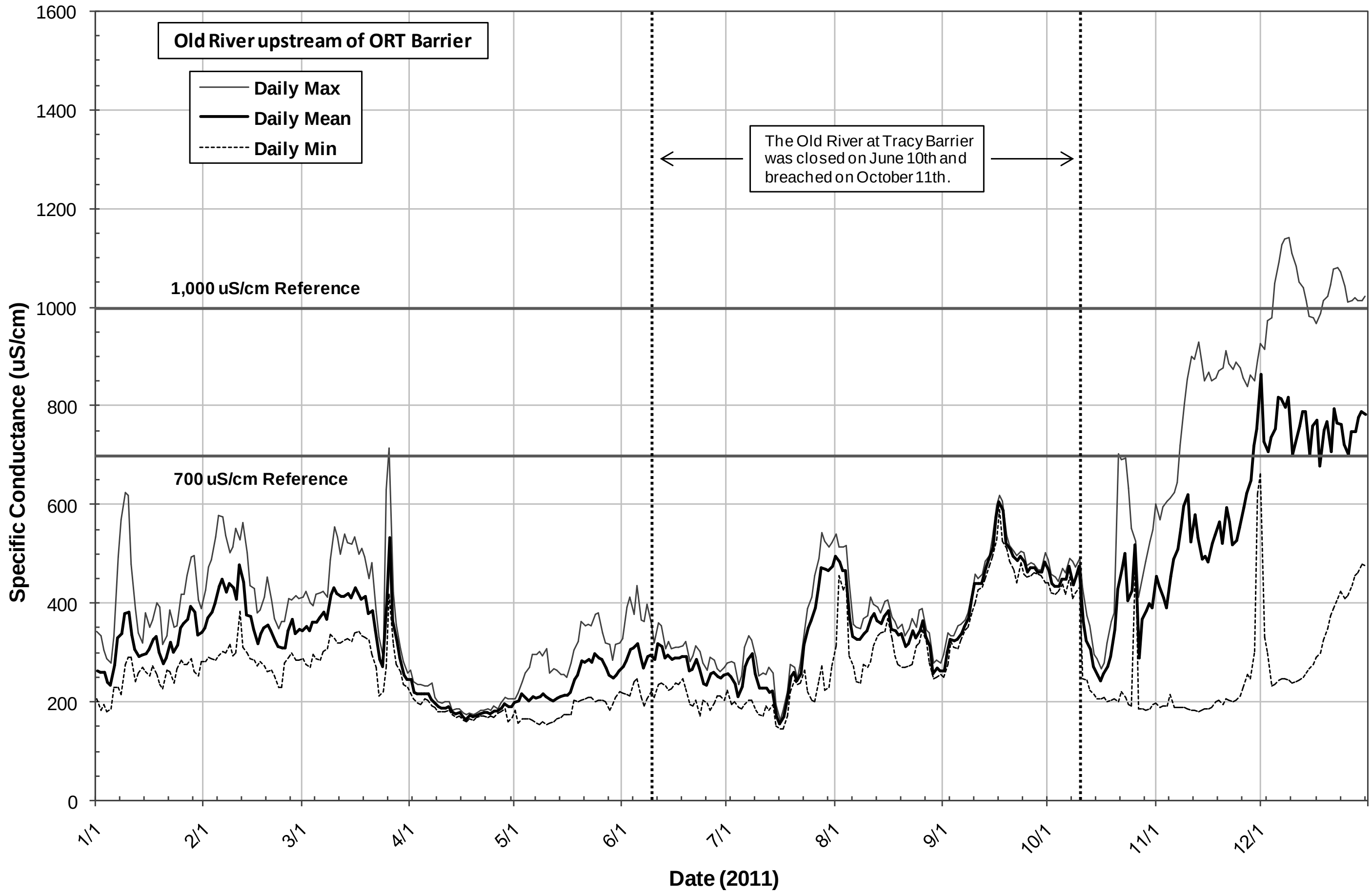


Figure 6-25: Daily Specific Conductance time-series graphs for the Old River stations



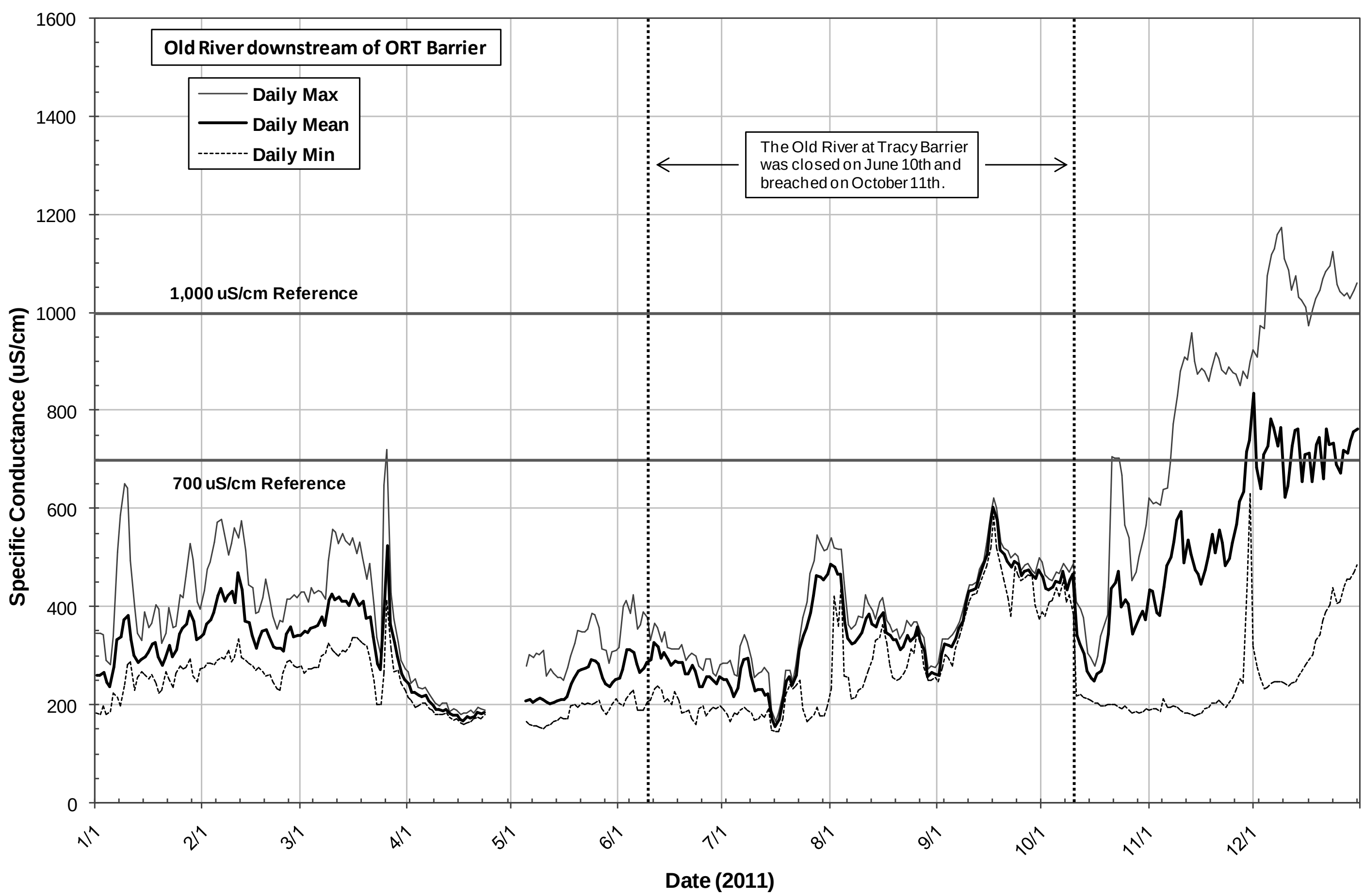
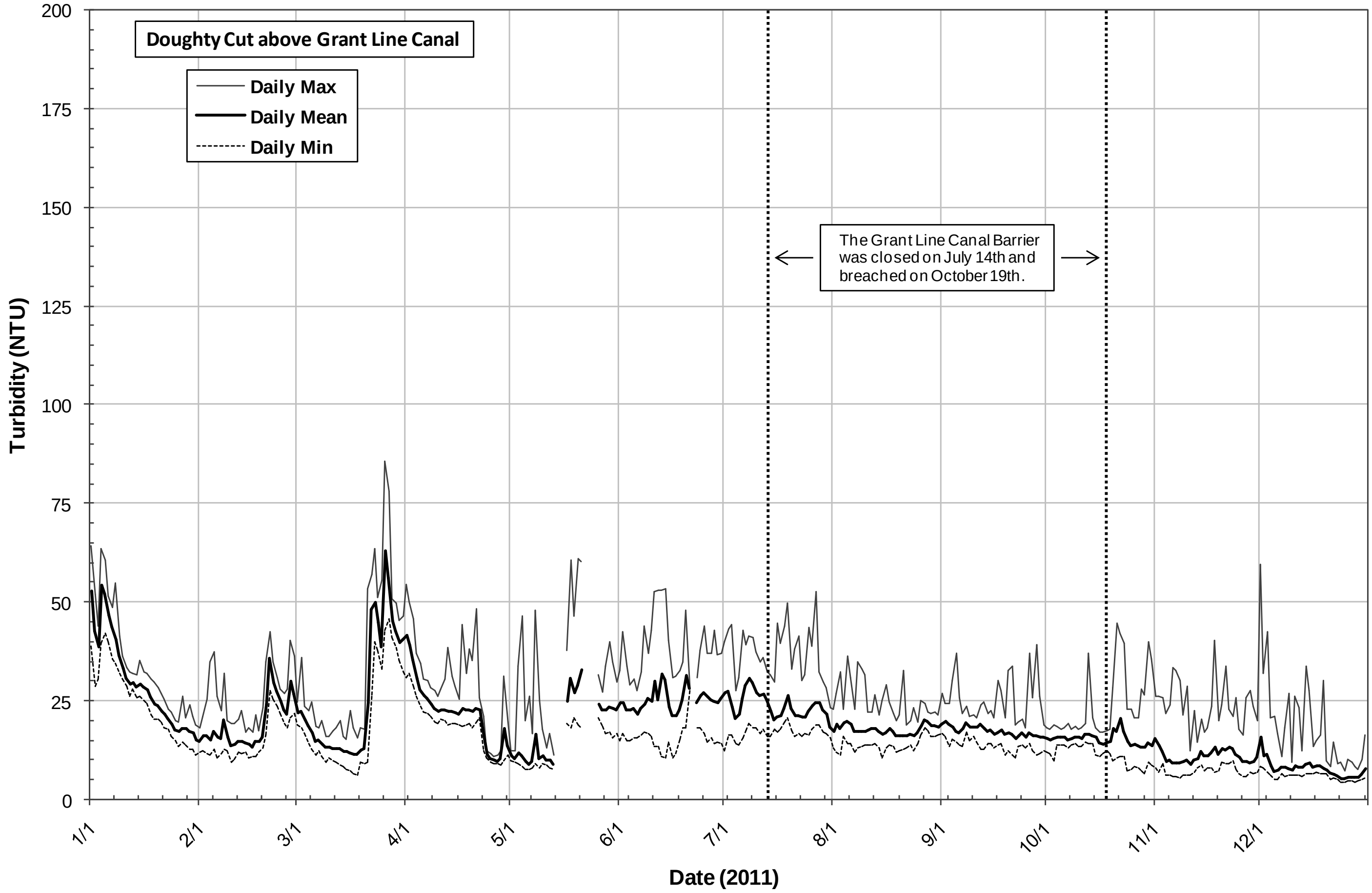


Figure 6-25: Daily Specific Conductance time-series graphs for the Old River stations

Turbidity

Turbidity in water is caused by suspended matter, such as clay, silt, organic and inorganic matter, plankton, and other microscopic organisms (APHA, 2005). Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample (APHA, 2005). In surface waters with reduced water clarity, phytoplankton and aquatic plant growth may be adversely affected because of reduced light penetration in the water column.

Turbidity values ranged from a high of 154.7 NTU on October 10th at Old River downstream of the ORT barrier to a low of 0.3 NTU on October 21st at Middle River at Union Point (Tables 6-3 to 6-6). Figures 6-26, 6-27, and 6-28 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively. Generally, single high turbidity spikes can be attributed to a foreign object, such as a leaf or fish passing before the optic sensors as the instrument is taking a reading. These anomalies are usually flagged as unreliable if a single value is greater than 200 NTU; however, there are times during the year where several continuous readings reveal a true event. At almost every South Delta station, there were three periods of time in 2011 with elevated turbidity values: in January at the very beginning of 2011, from mid-February to the beginning of March, and from mid-March to the beginning of April. This was most likely due to multiple large storm events that caused an increase in suspended sediment in these water bodies. Besides these increases in turbidity values during the winter and early spring of 2011, some of the South Delta stations appeared to have slightly elevated turbidity values during the summer months (Figures 6-26 to 6-28). The stations with the highest turbidity values in 2011 were Doughty Cut above Grant Line Canal, Middle River at Undine Road, Middle River at Howard Road, Old River at Head, and Old River at Tracy Wildlife Association. Middle River at Union Point and Victoria Canal had the lowest turbidity values in 2011.



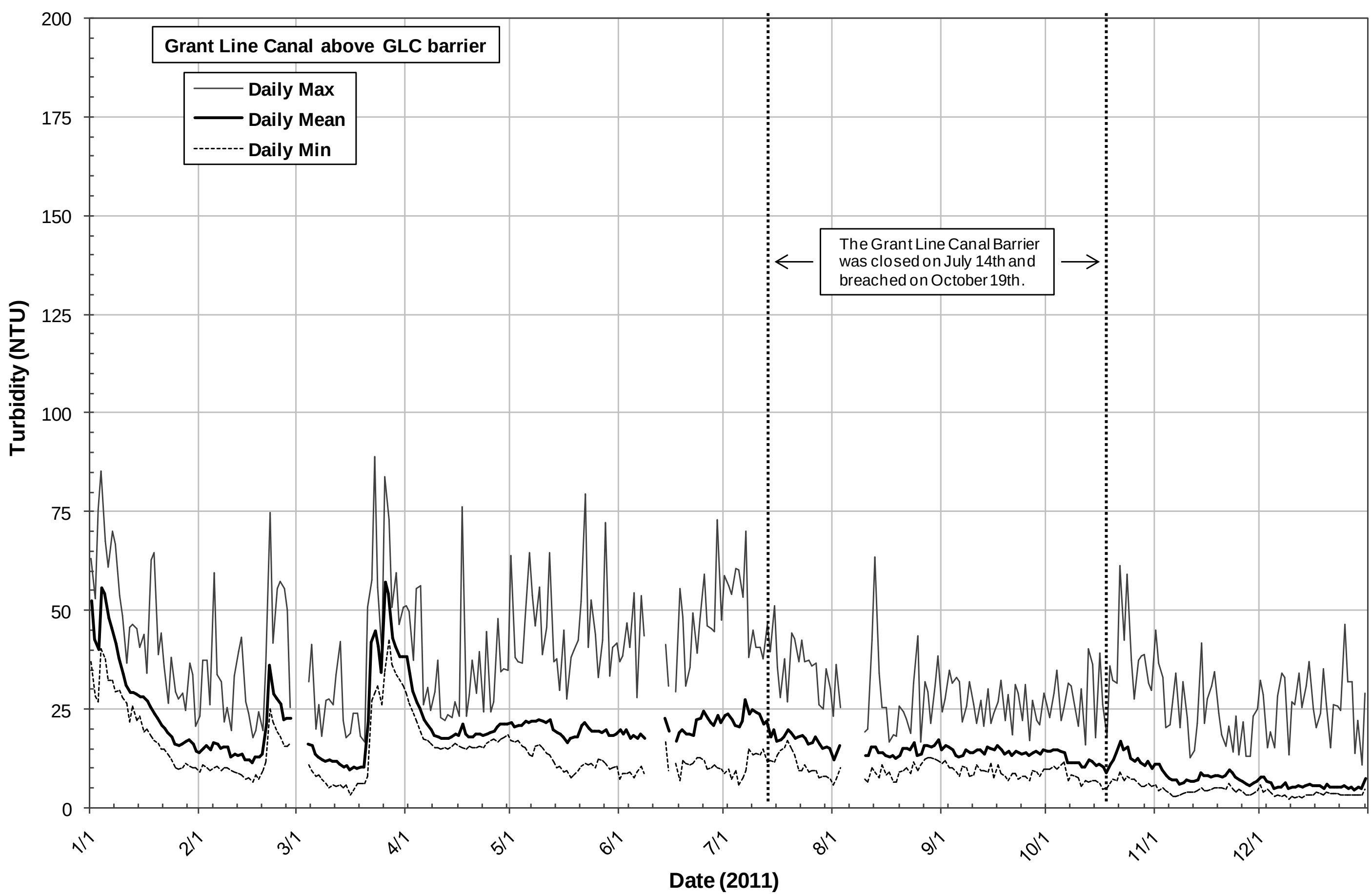
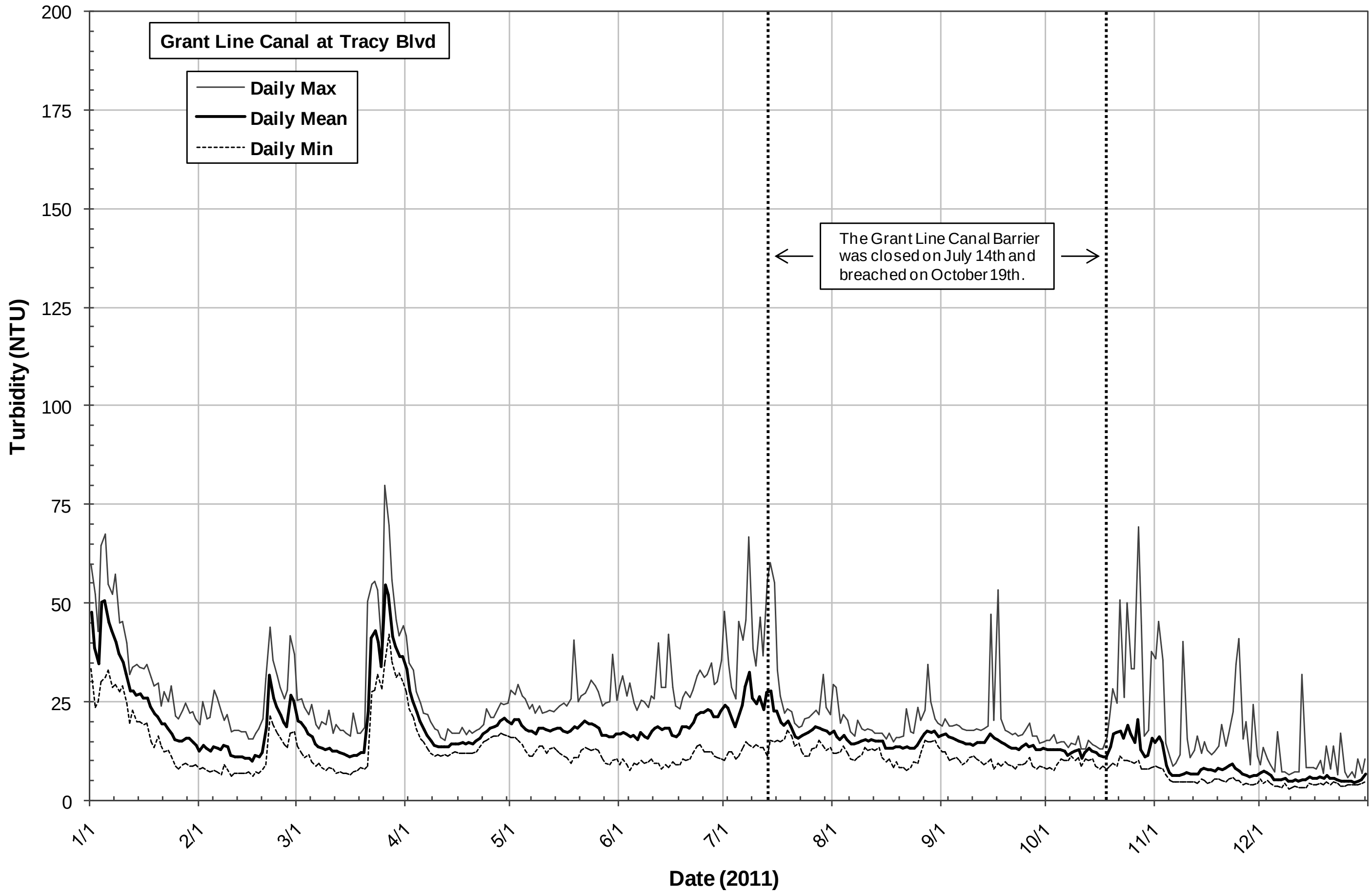


Figure 6-26: Daily Turbidity time-series graphs for the Grant Line and Victoria Canal stations



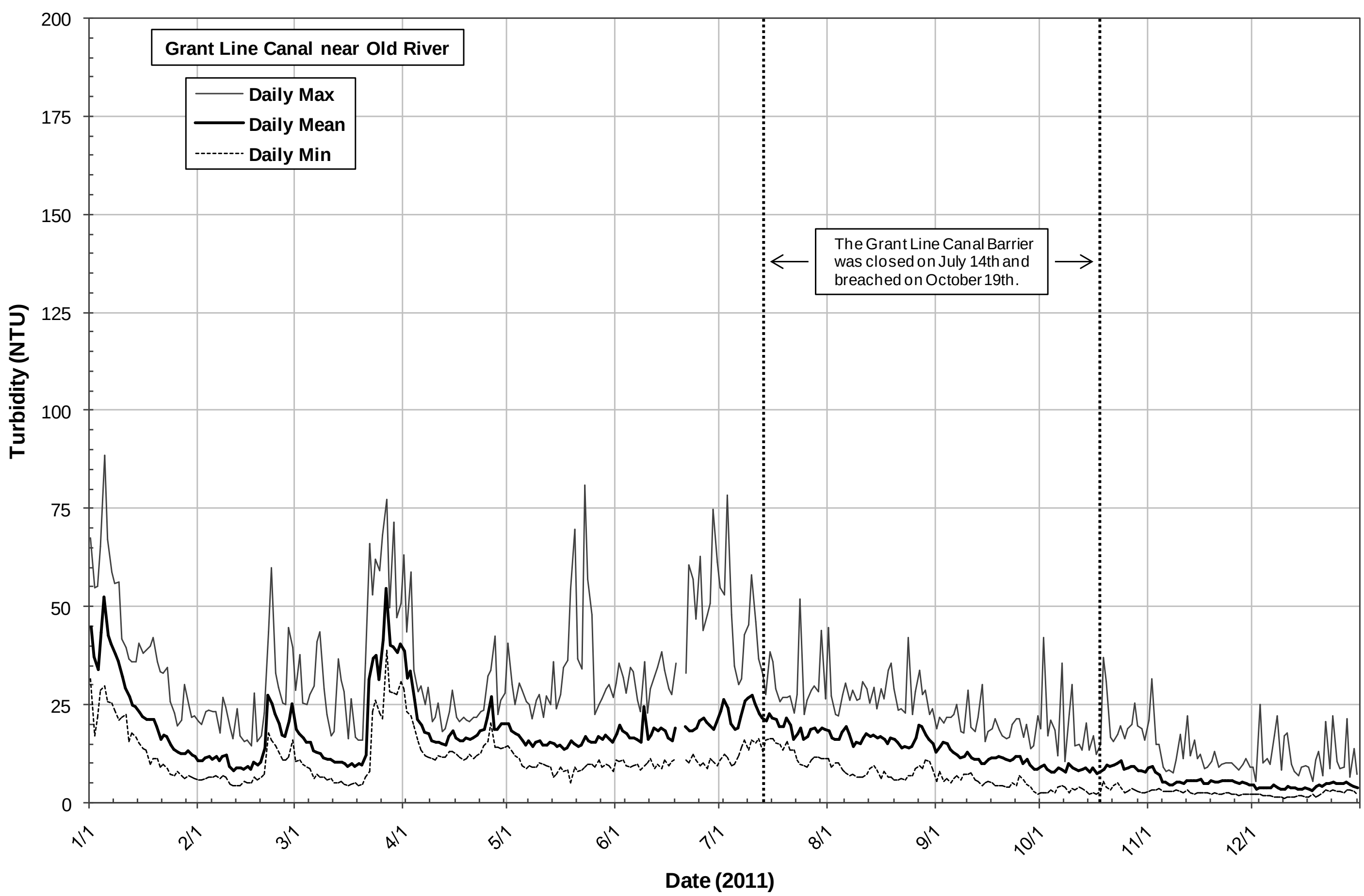


Figure 6-26: Daily Turbidity time-series graphs for the Grant Line and Victoria Canal stations

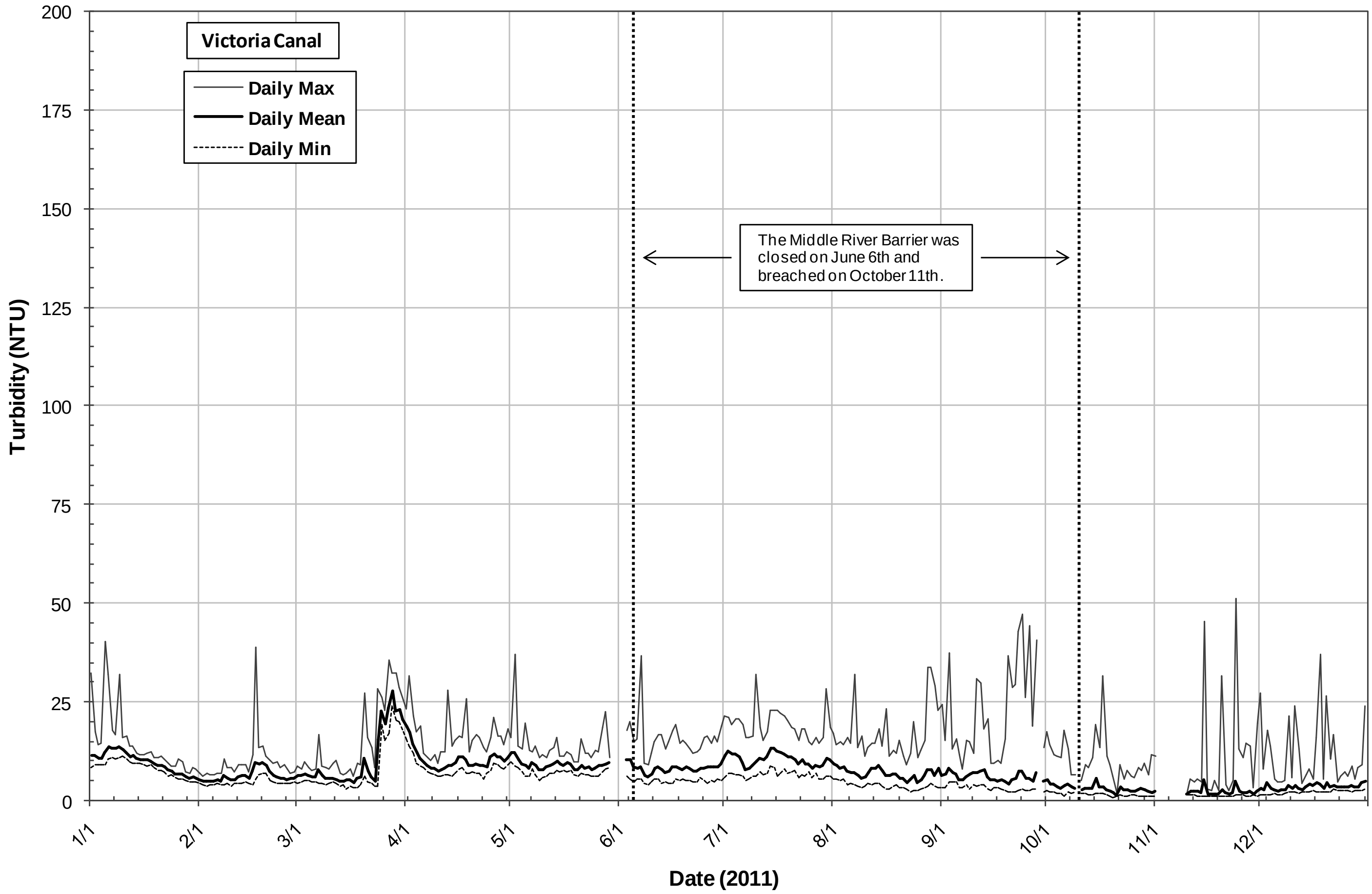
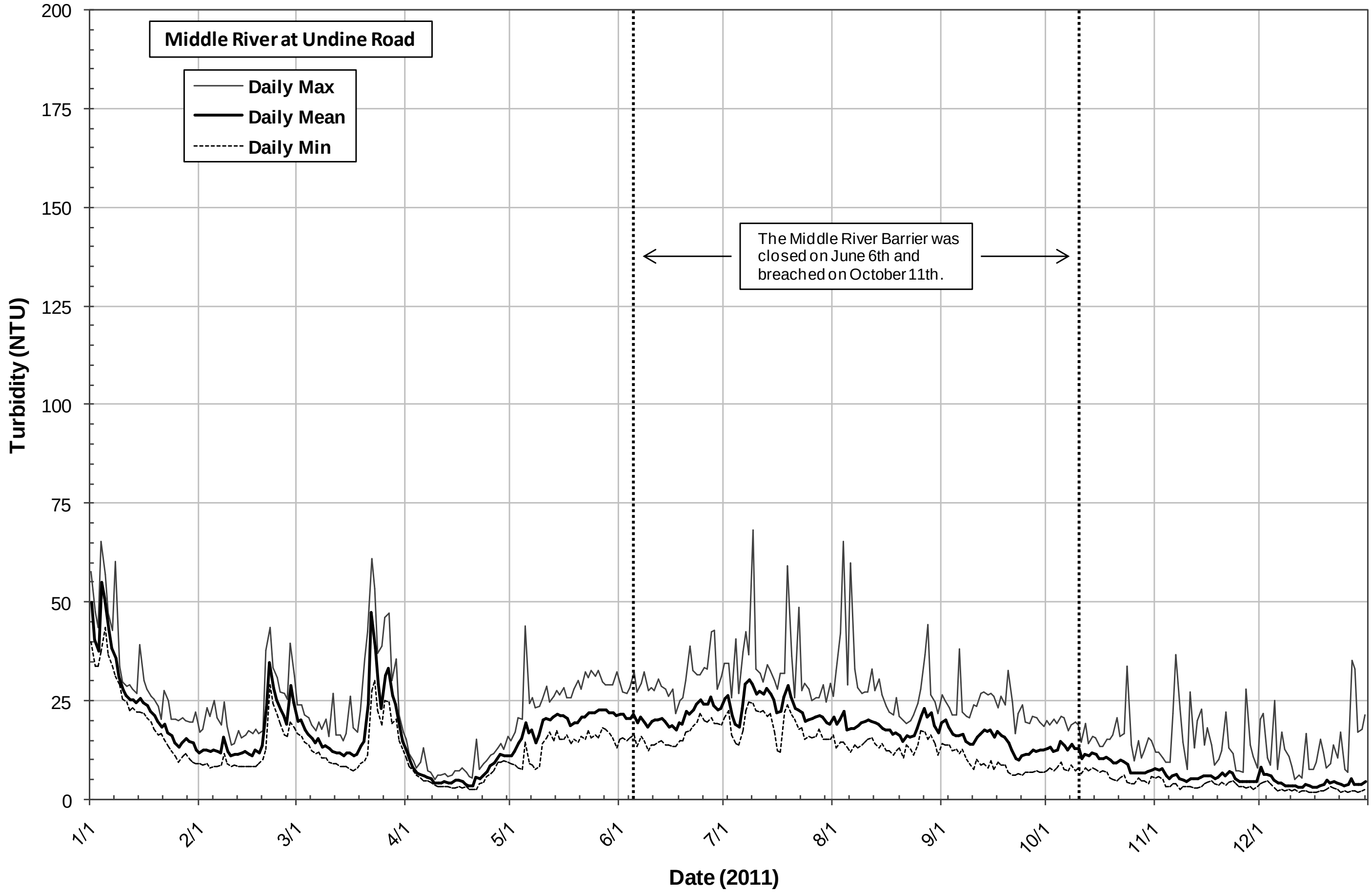


Figure 6-26: Daily Turbidity time-series graphs for the Grant Line and Victoria Canal stations



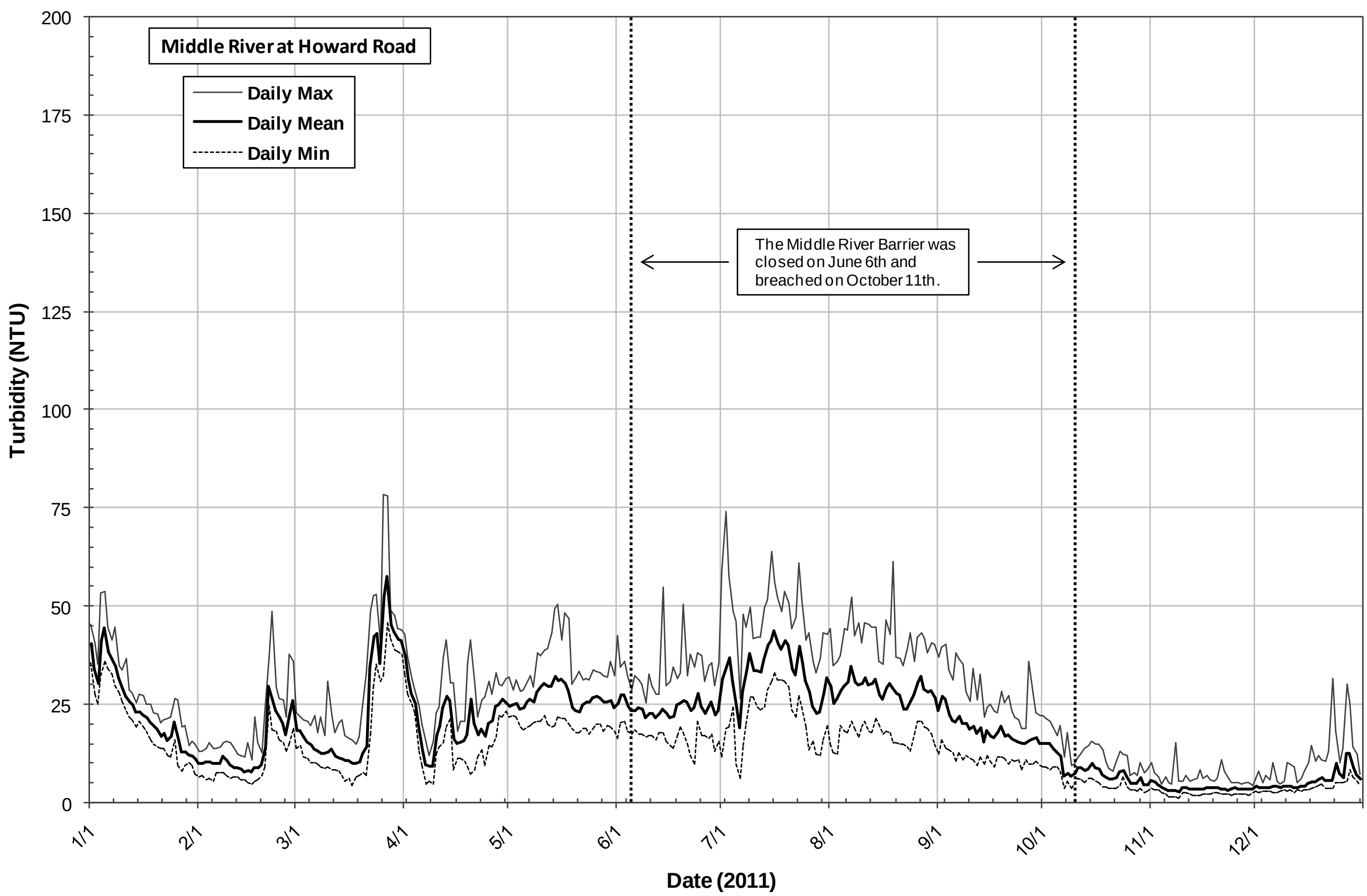
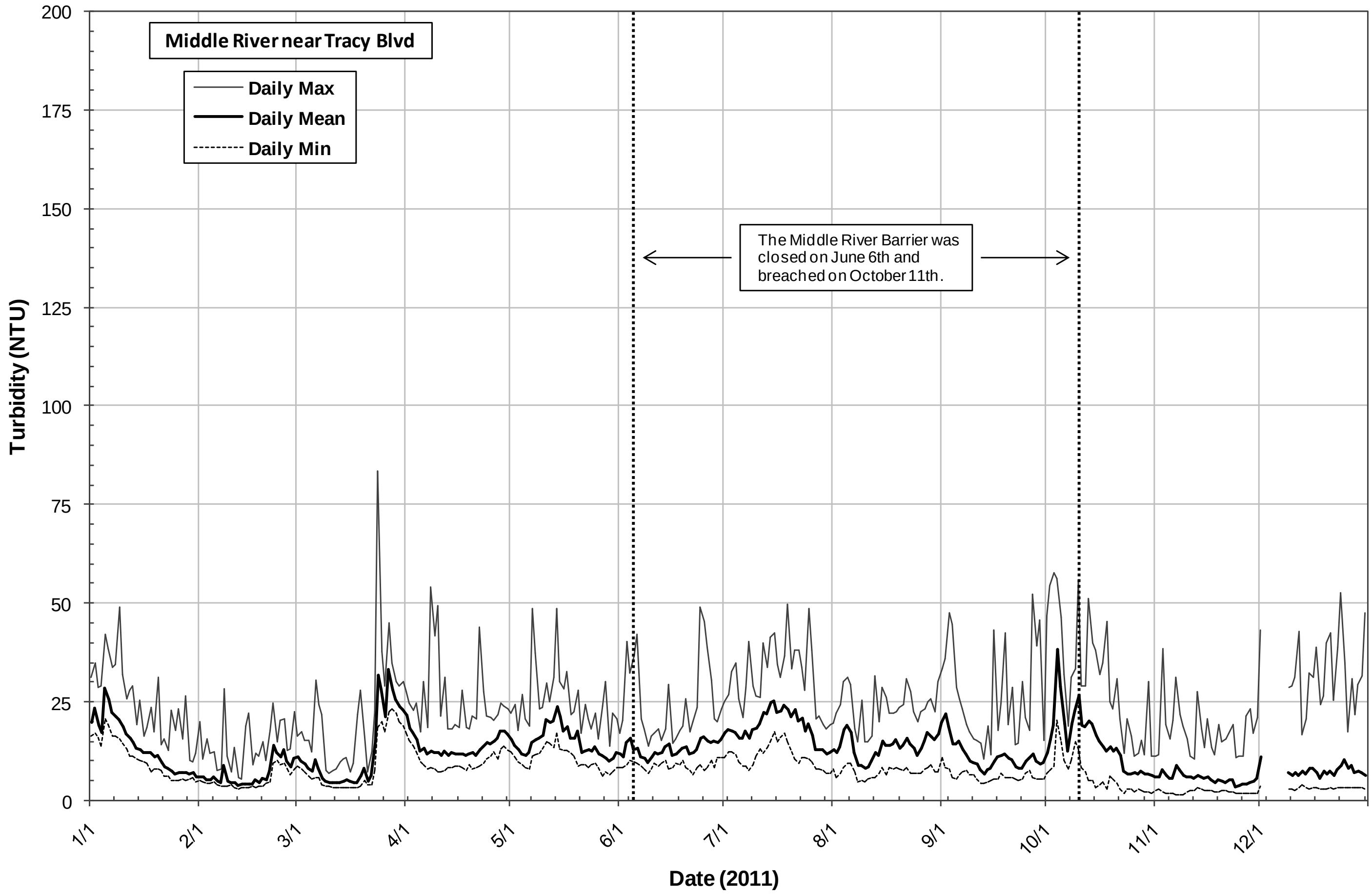


Figure 6-27: Daily Turbidity time-series graphs for the Middle River stations



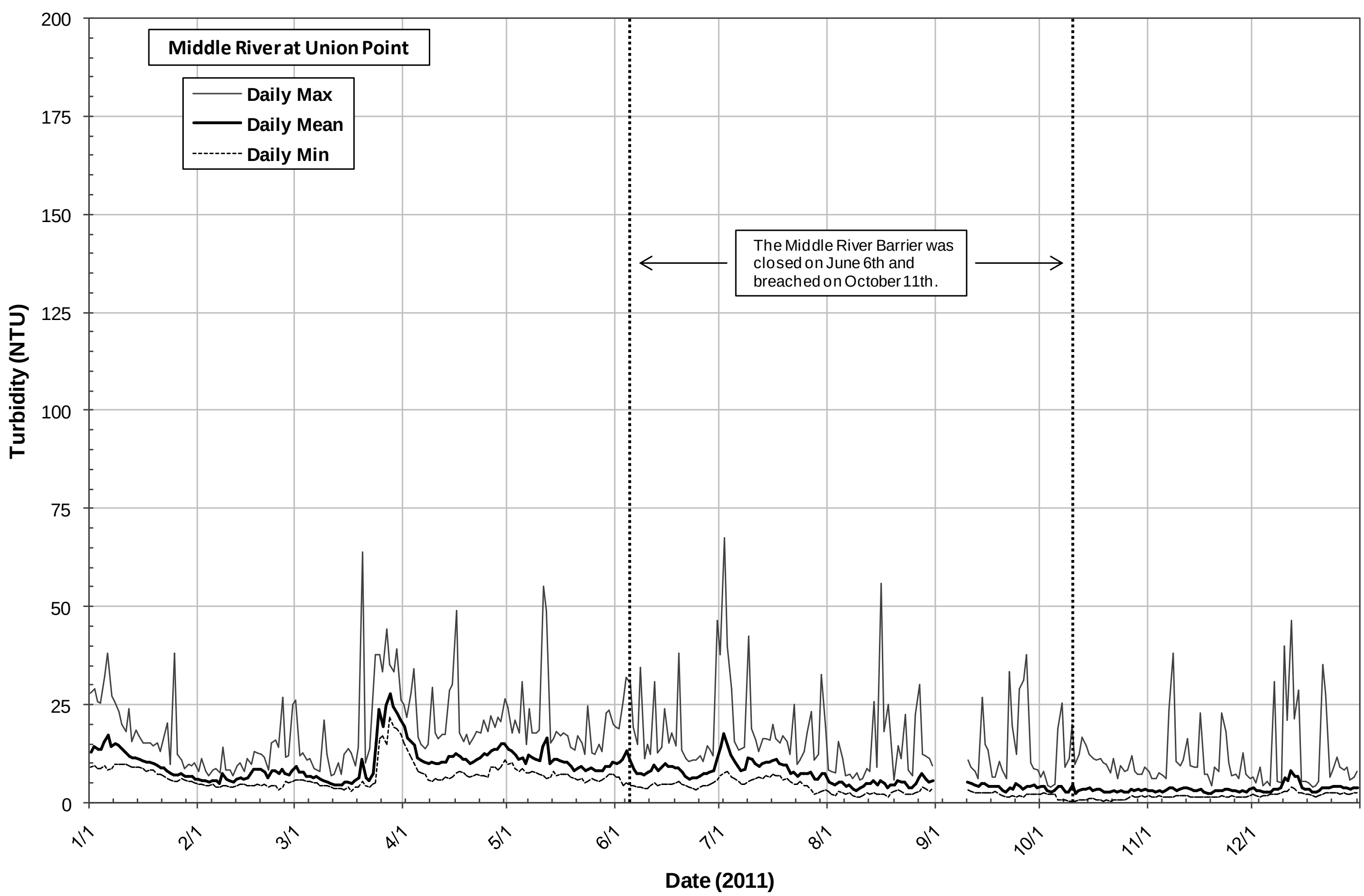
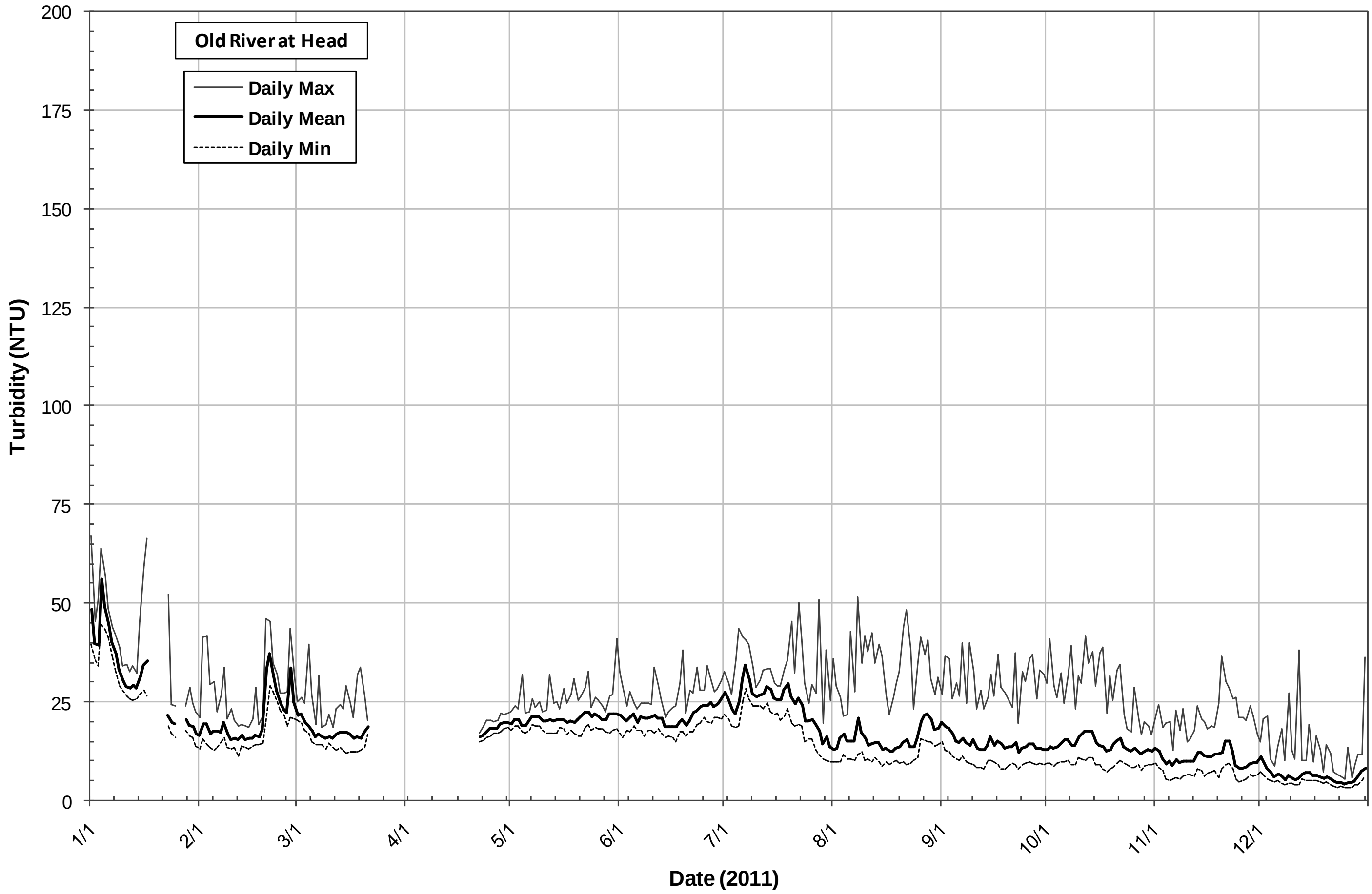


Figure 6-27: Daily Turbidity time-series graphs for the Middle River stations



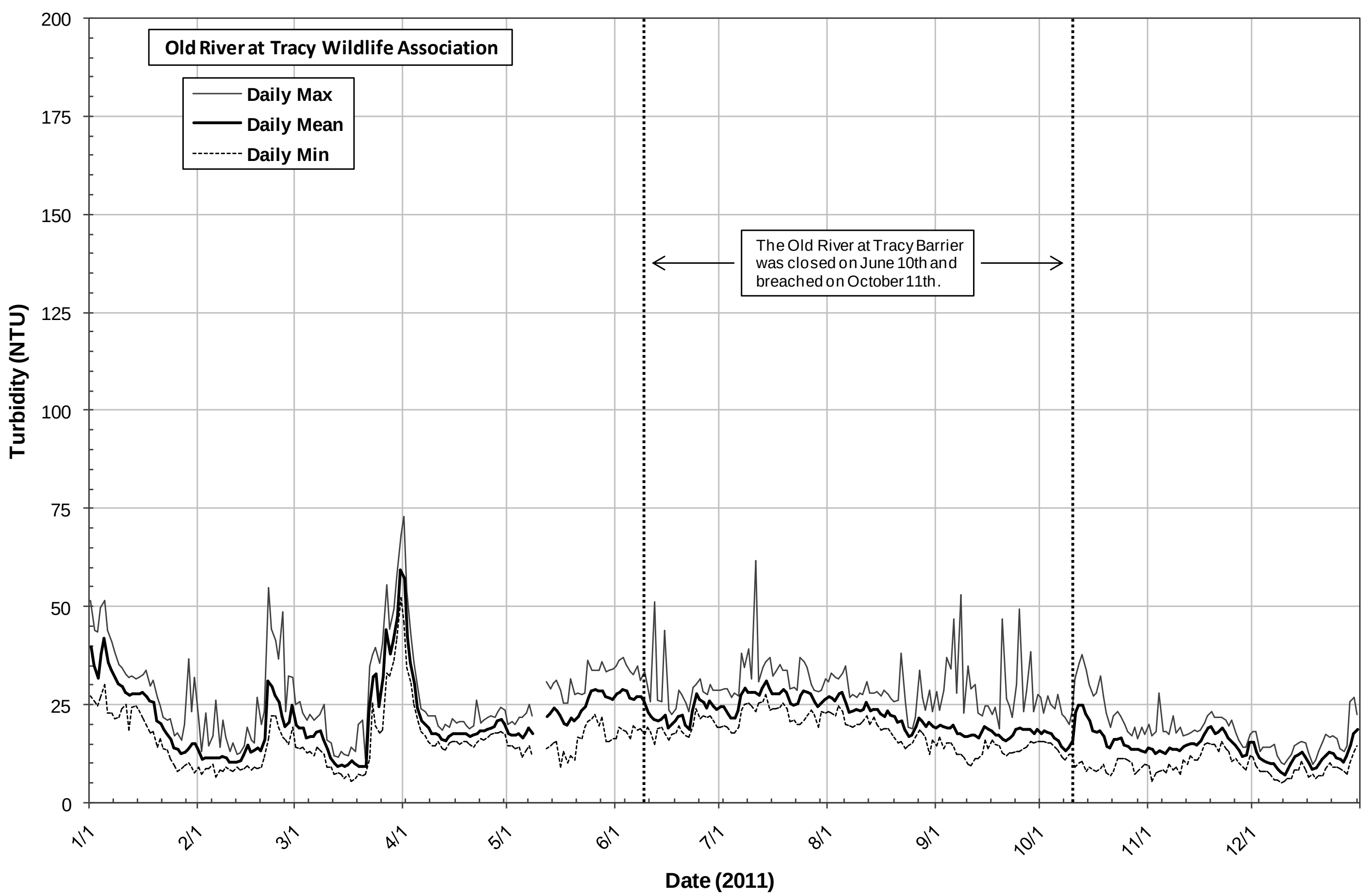
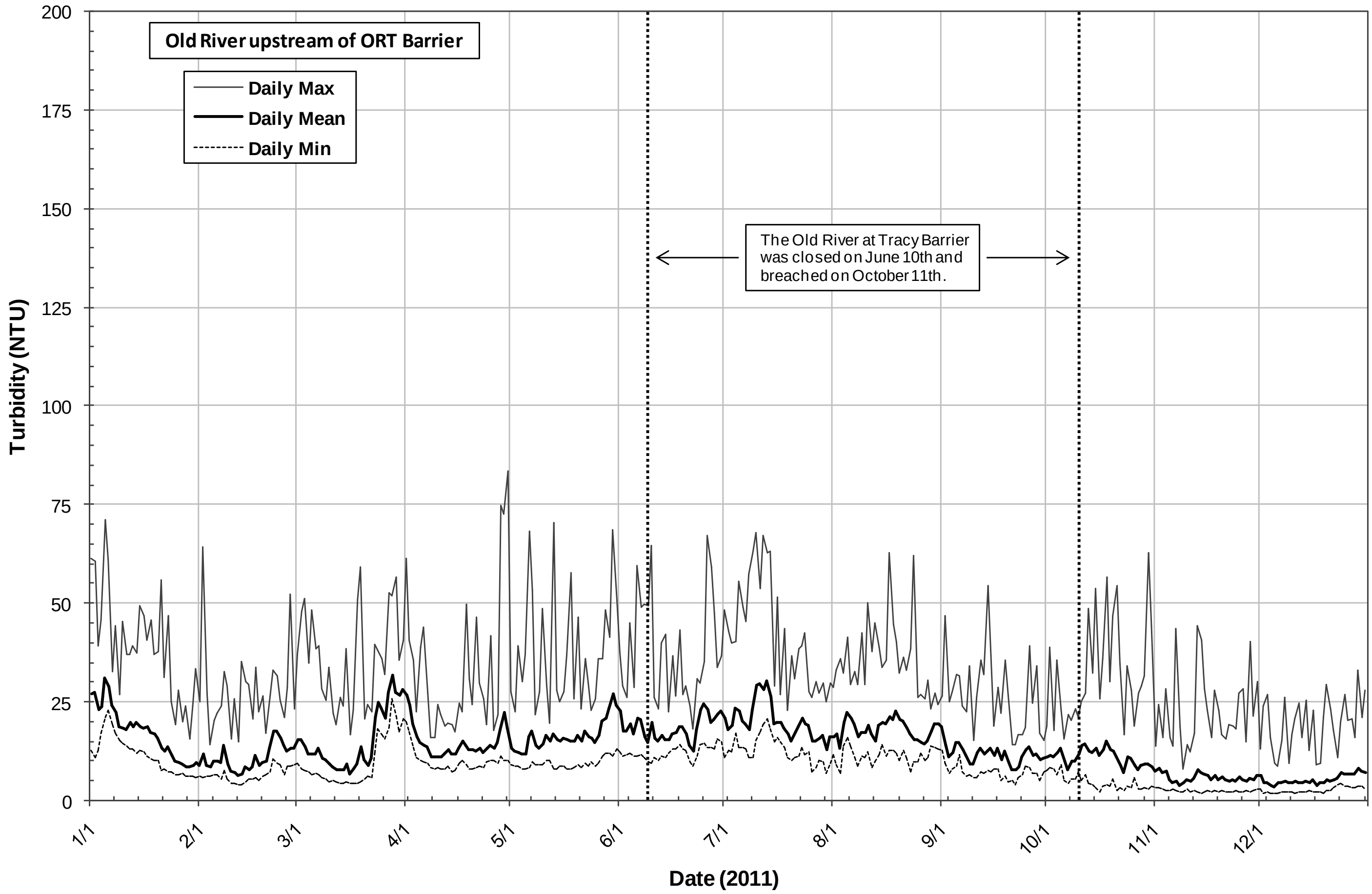


Figure 6-28: Daily Turbidity time-series graphs for the Old River stations



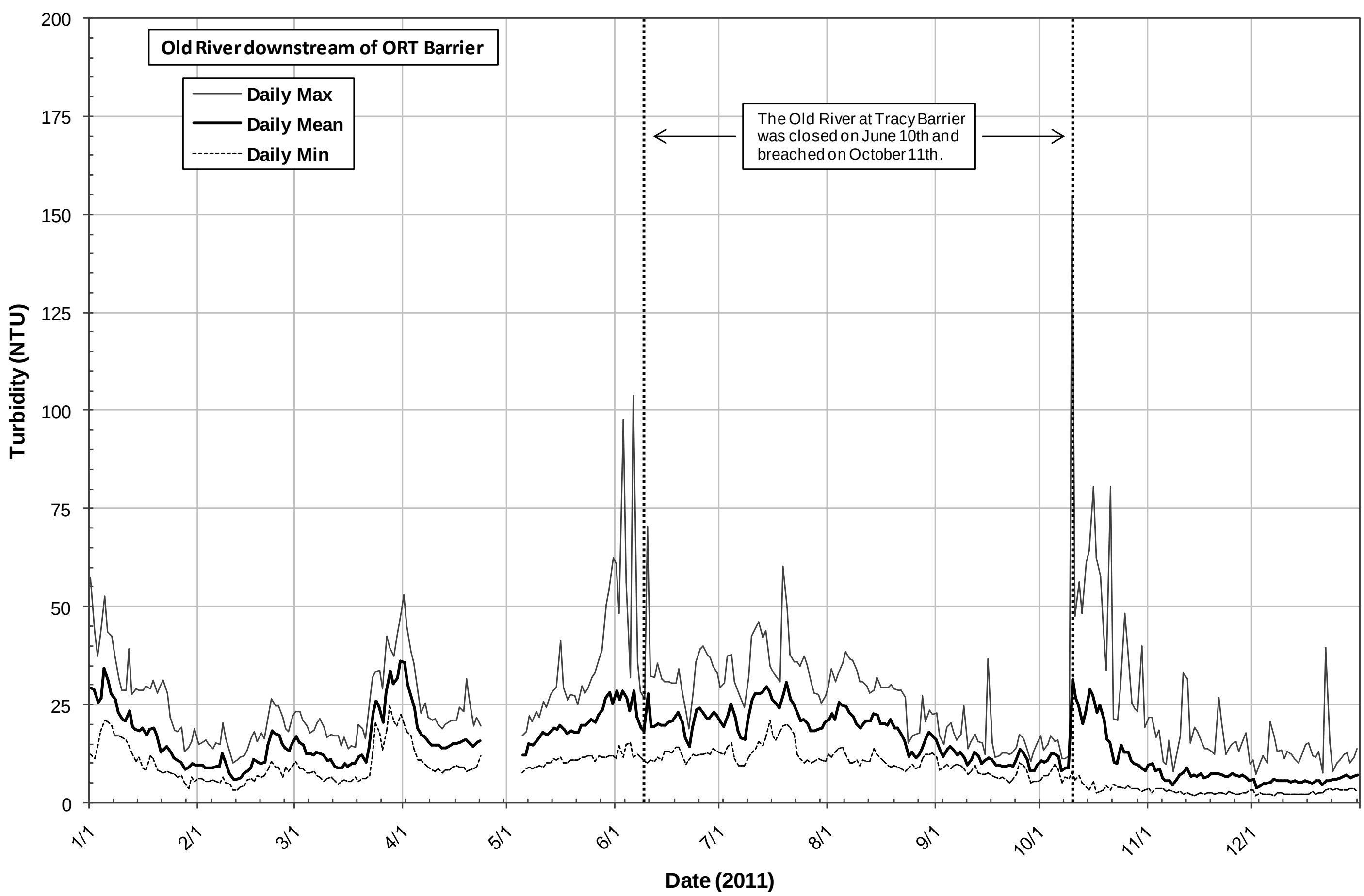


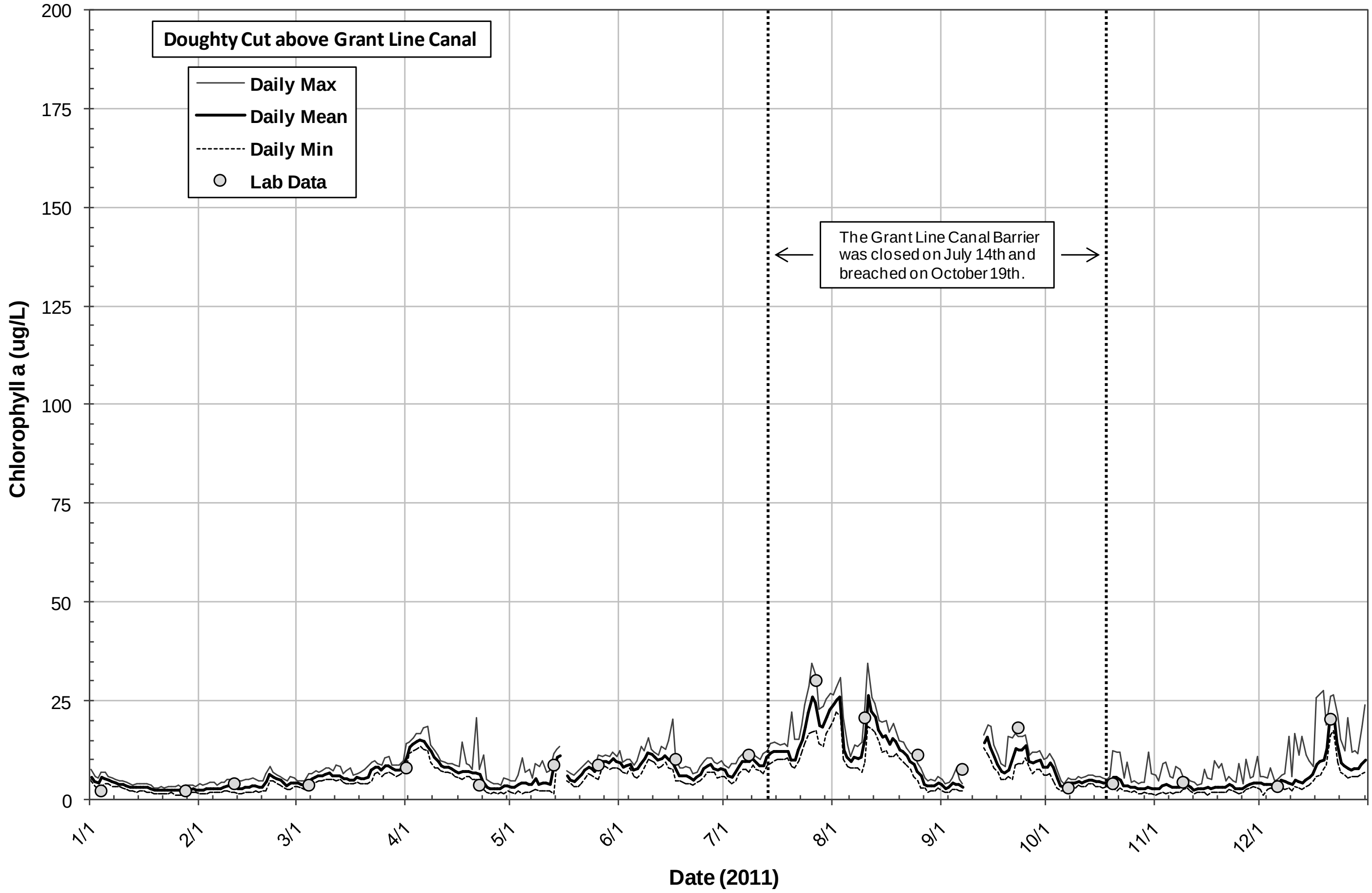
Figure 6-28: Daily Turbidity time-series graphs for the Old River stations

Chlorophyll *a*

Chlorophyll *a* concentrations can be used as an indicator of phytoplankton biomass in a water body (APHA, 2005). Phytoplankton (microscopic algae) occur as unicellular, colonial, or filamentous forms and are primarily grazed upon by zooplankton and other aquatic organisms (APHA, 2005). The species composition and/or biomass of phytoplankton may be a useful tool in assessing water quality (APHA, 2005). Algae can influence water quality by affecting: pH, dissolved oxygen, turbidity, the color, taste and odor of water, and under certain conditions, some species can develop noxious blooms.

Staff adjusted the chlorophyll *a* concentrations measured by the optical probes by using the procedures discussed in the Materials and Methods section of this chapter. Adjusted chlorophyll *a* concentrations ranged from a high of 148.6 µg/L on December 27th at Old River downstream of the ORT barrier to a low of 0 µg/L on various occasions at four stations (Tables 6-3 to 6-6). Figures 6-29, 6-30, and 6-31 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively.

The four stations along Grant Line Canal, Middle River at Undine Road, Middle River at Howard Road, and the four stations along Old River all displayed a similar trend in adjusted chlorophyll *a* concentrations throughout 2011. At all of these stations, adjusted chlorophyll *a* concentrations were slightly elevated during two distinct periods: once in the summer during the month of August and the other during the winter from the beginning of December through the end of the year. Median monthly chlorophyll *a* concentrations ranged from 4.3 µg/L to 25.2 µg/L in the summer at these stations (Tables 6-3 to 6-6). Typically, chlorophyll *a* concentrations significantly increase during the spring months at most South Delta stations; however, during 2011 only a few stations had slightly higher chlorophyll *a* concentrations during the spring. This unusual trend may have been partially due to the cool and extremely wet spring in 2011. No obvious increases in adjusted chlorophyll *a* concentrations were observed at Victoria Canal, Middle River near Tracy Blvd, and Middle River at Union Point throughout the entire year. Adjusted chlorophyll *a* concentrations remained relatively constant in 2011 with an average of approximately 3 µg/L at these stations.



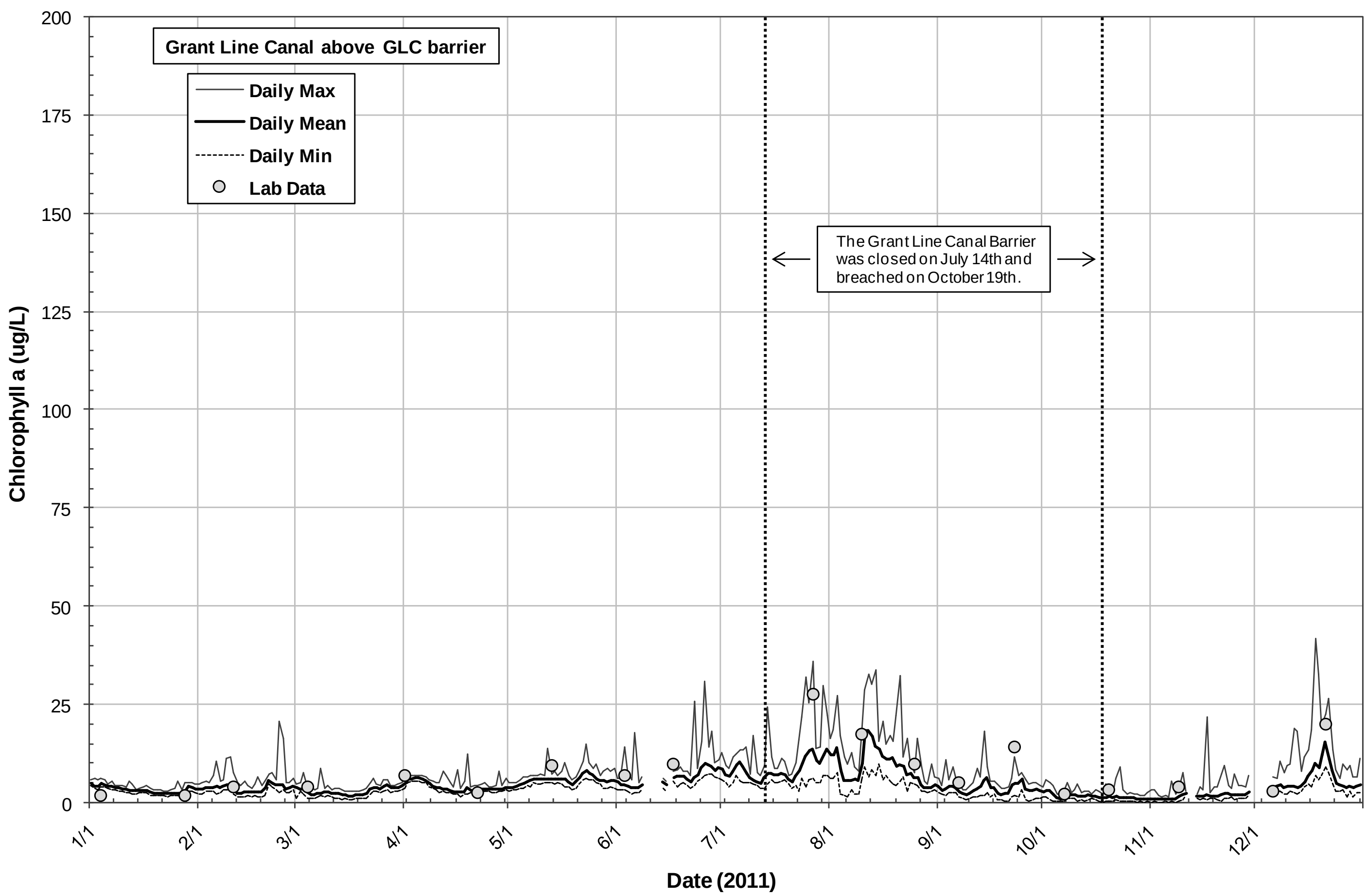


Figure 6-29: Daily Chlorophyll *a* time-series graphs for the Grant Line and Victoria Canal stations

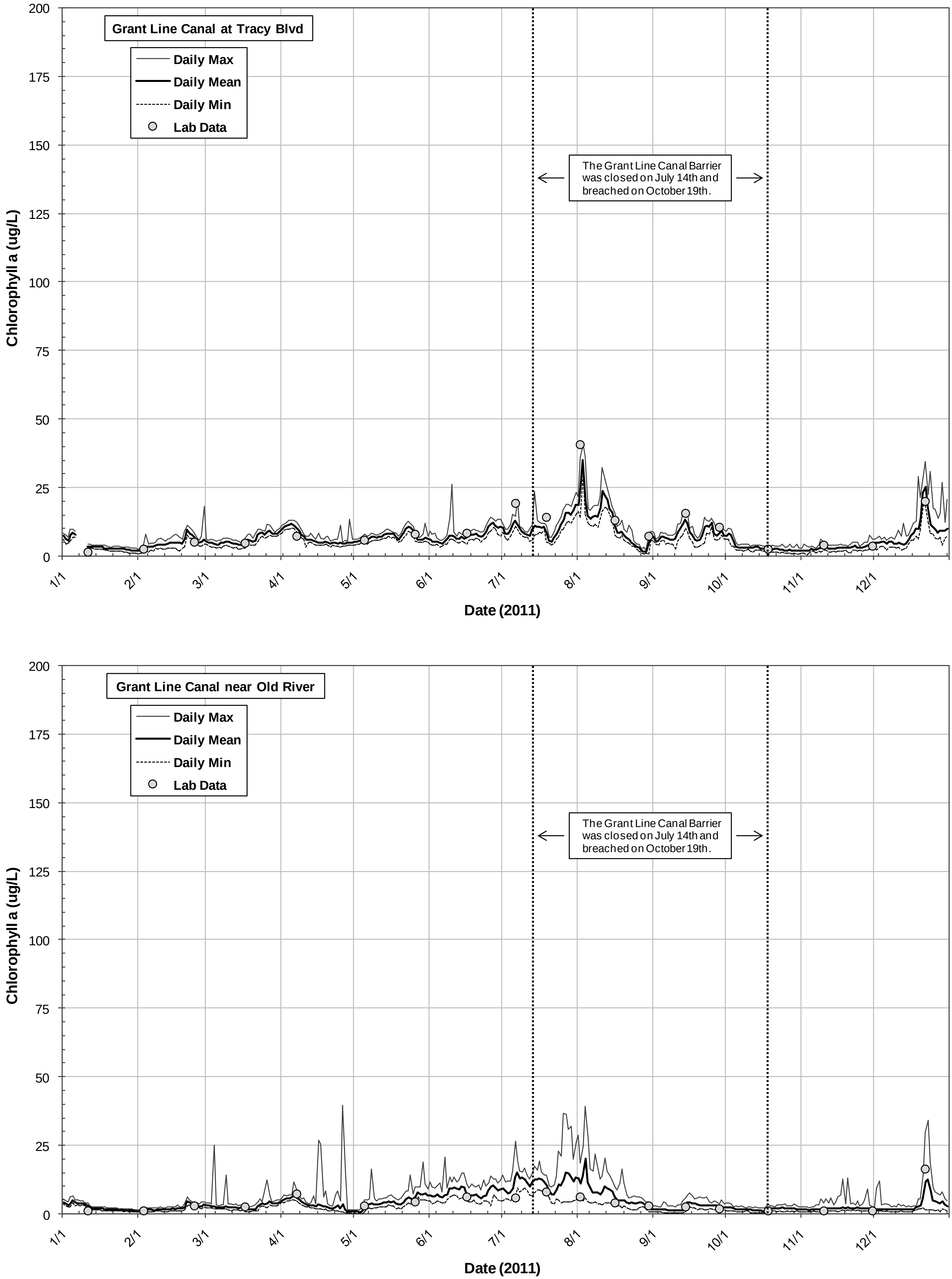


Figure 6-29: Daily Chlorophyll *a* time-series graphs for the Grant Line and Victoria Canal stations

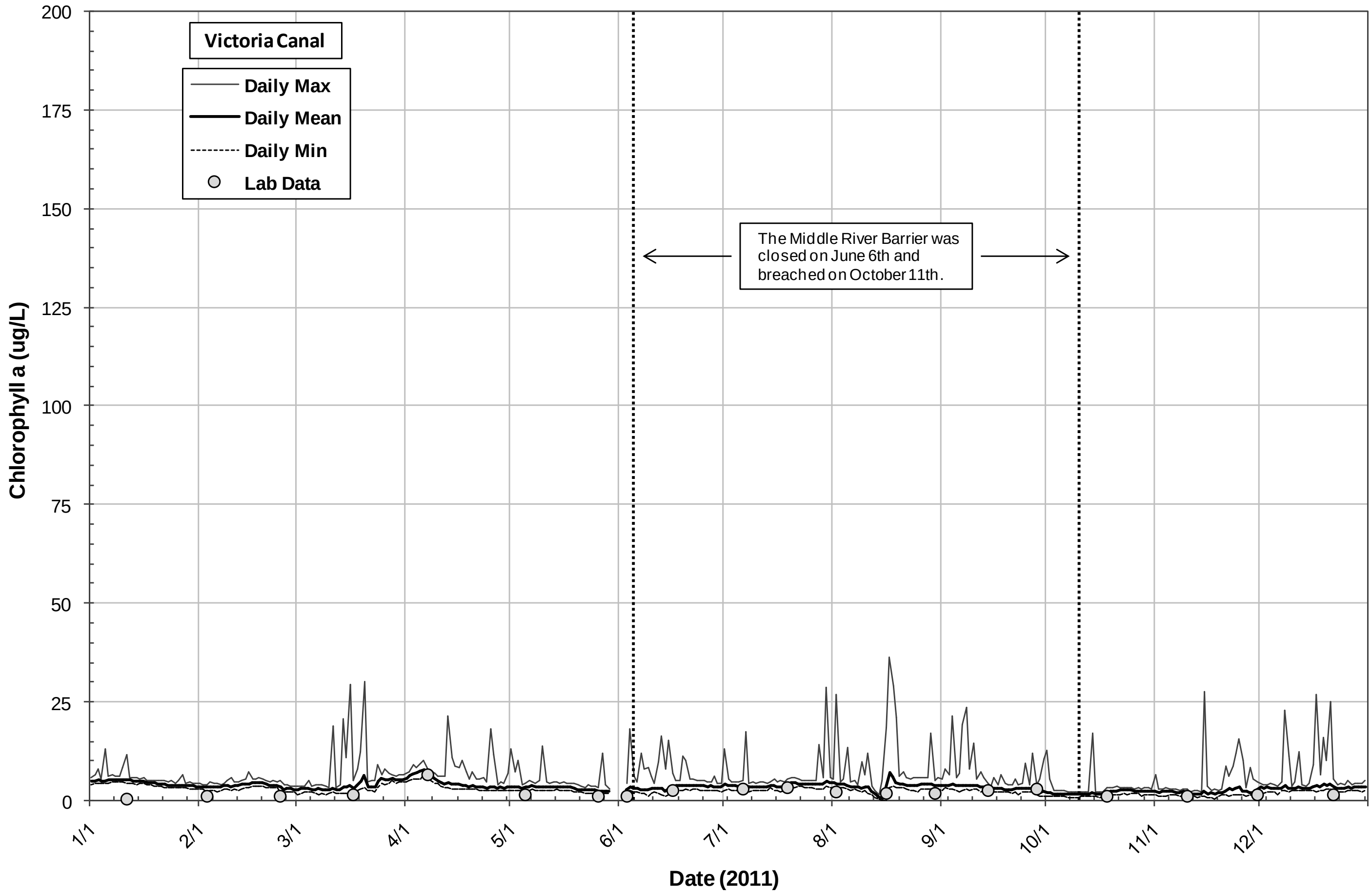
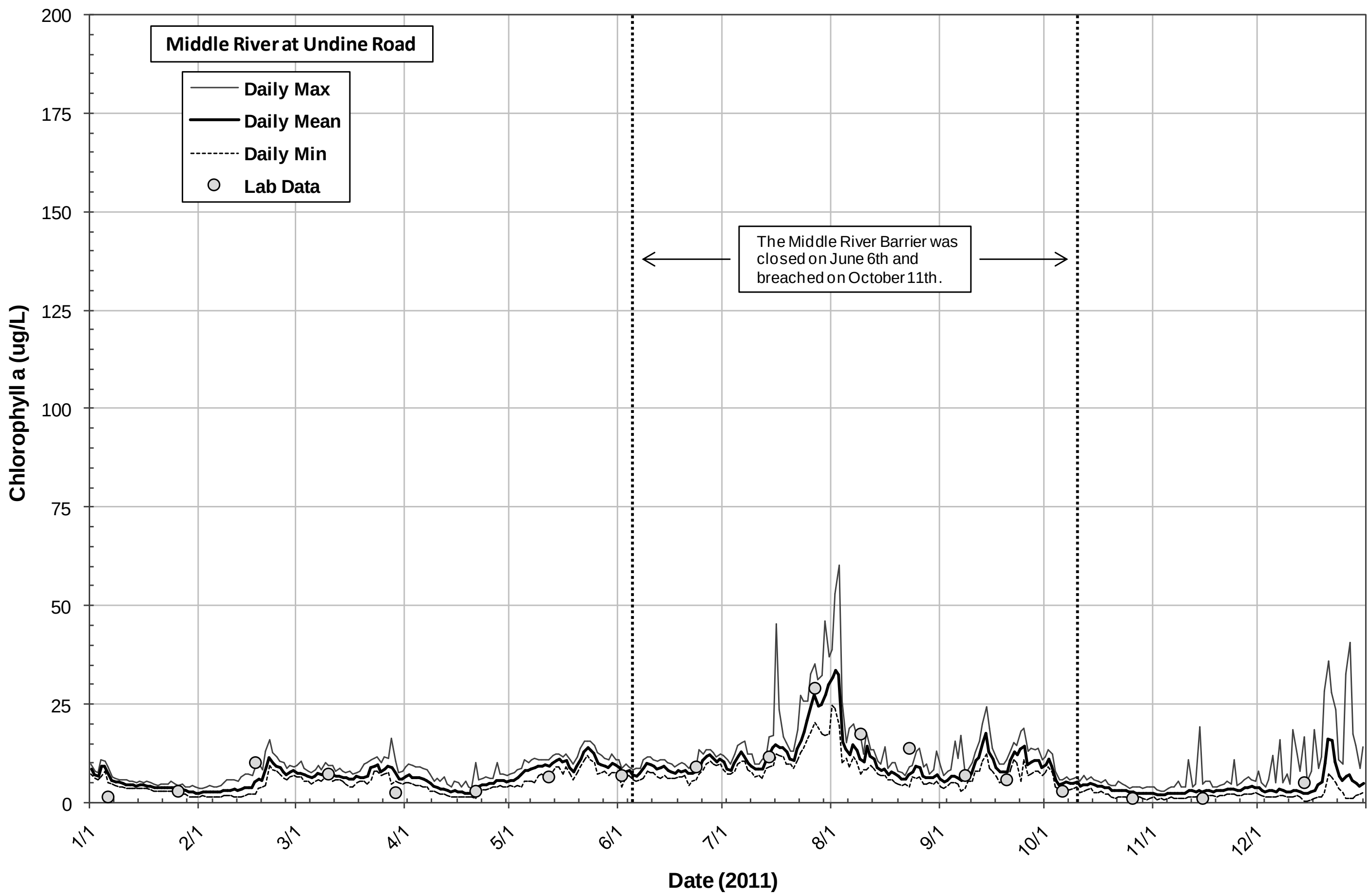


Figure 6-29: Daily Chlorophyll *a* time-series graphs for the Grant Line and Victoria Canal stations



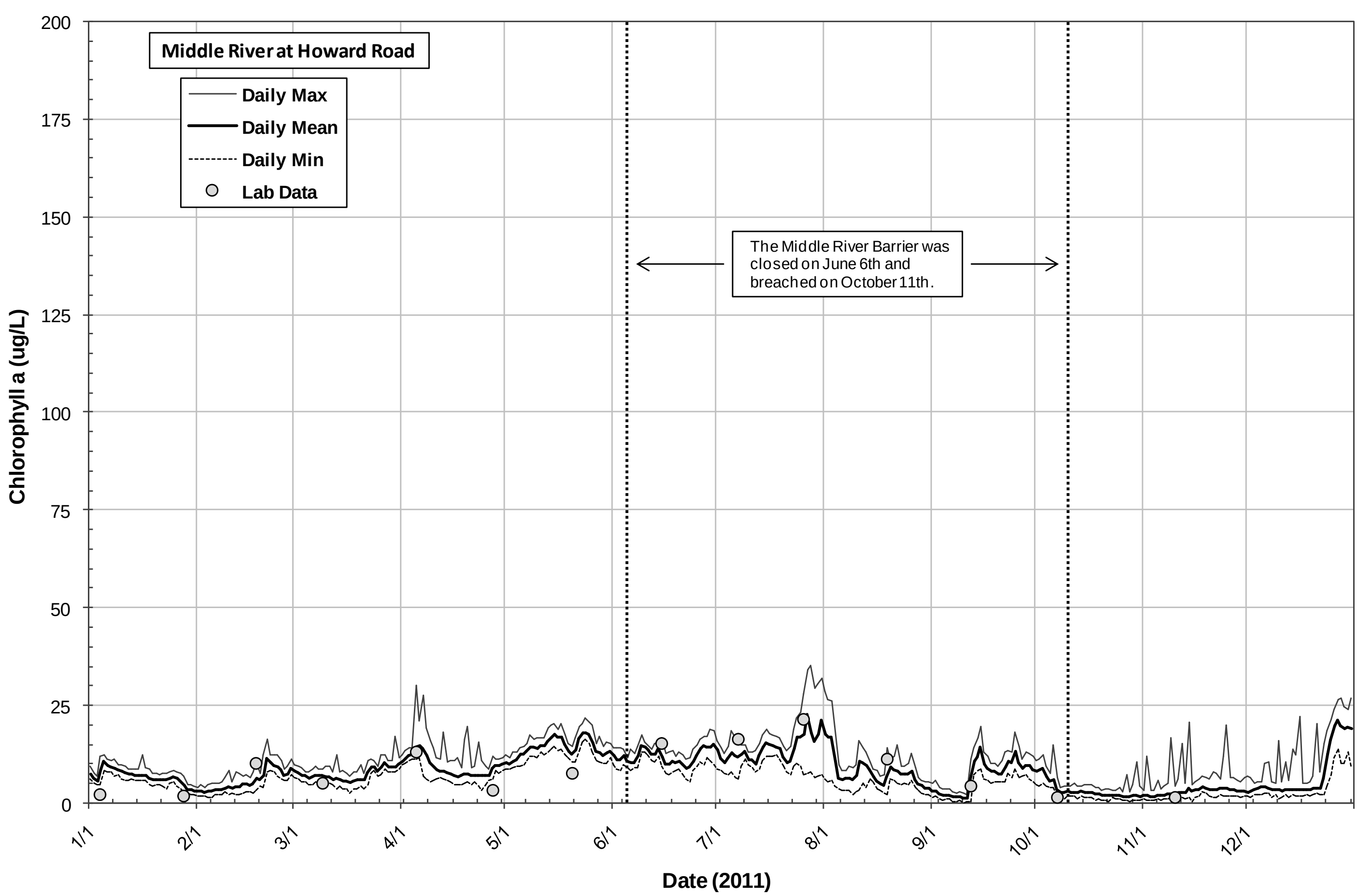
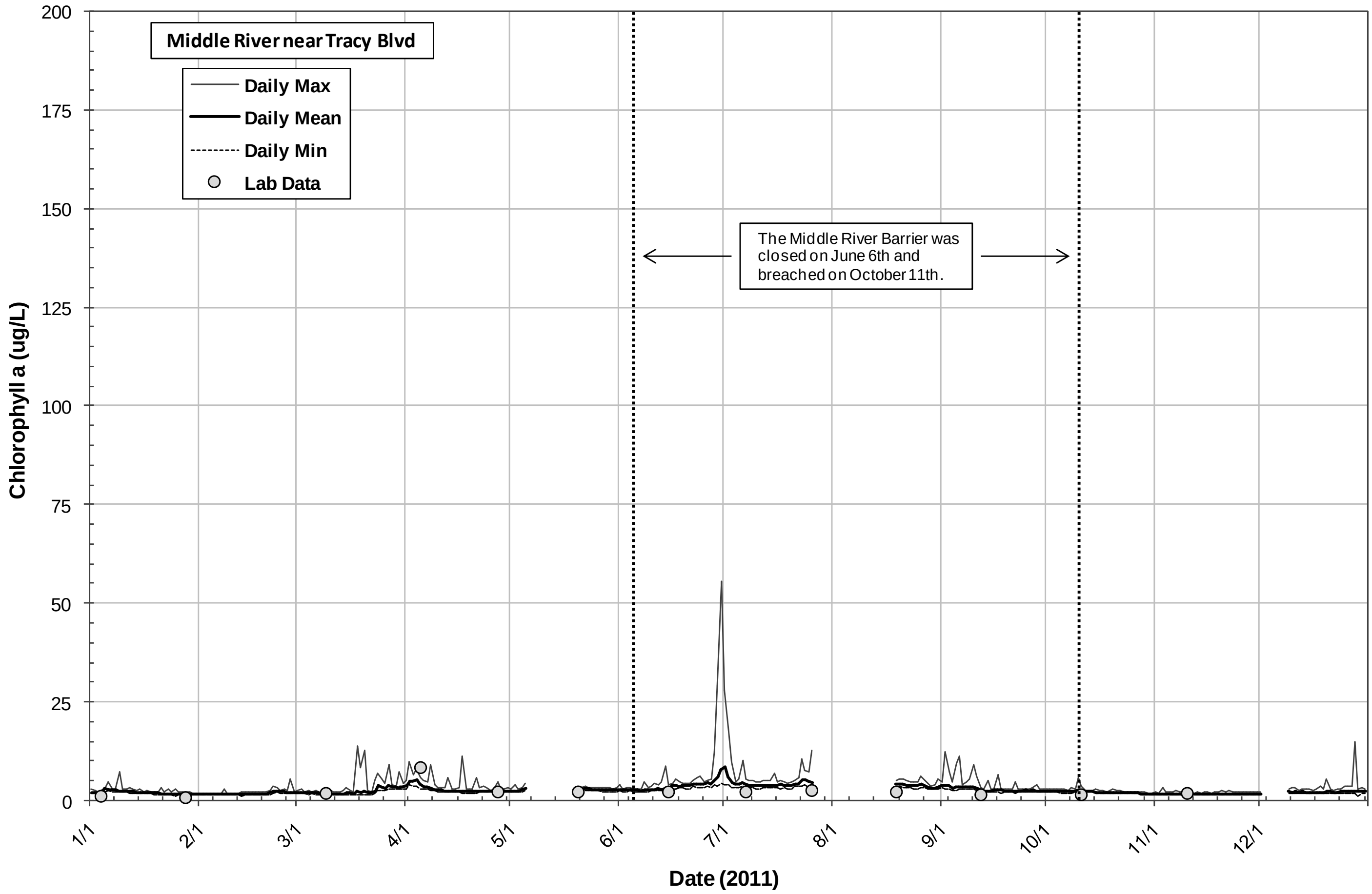


Figure 6-30: Daily Chlorophyll *a* time-series graphs for the Middle River stations



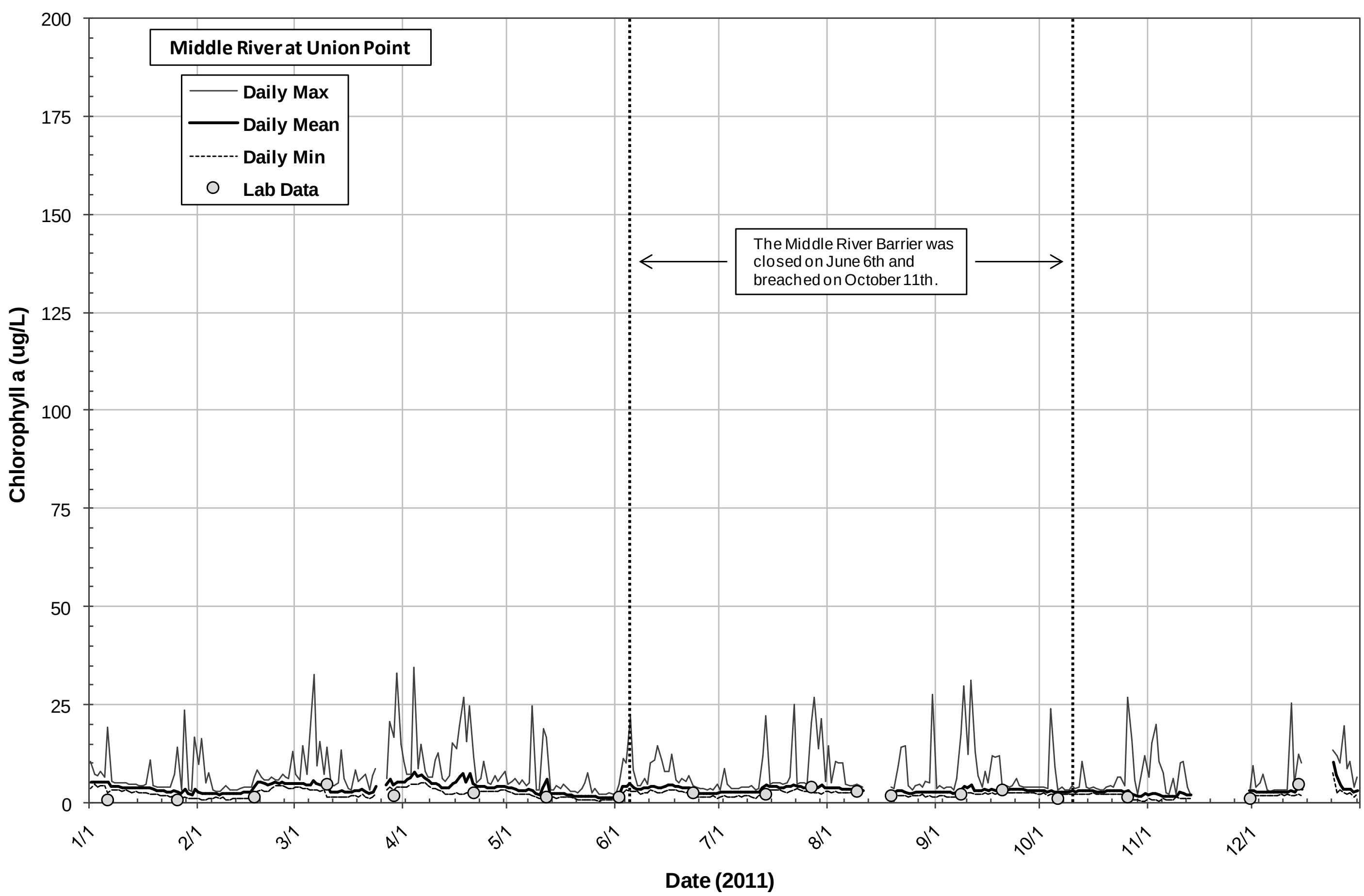
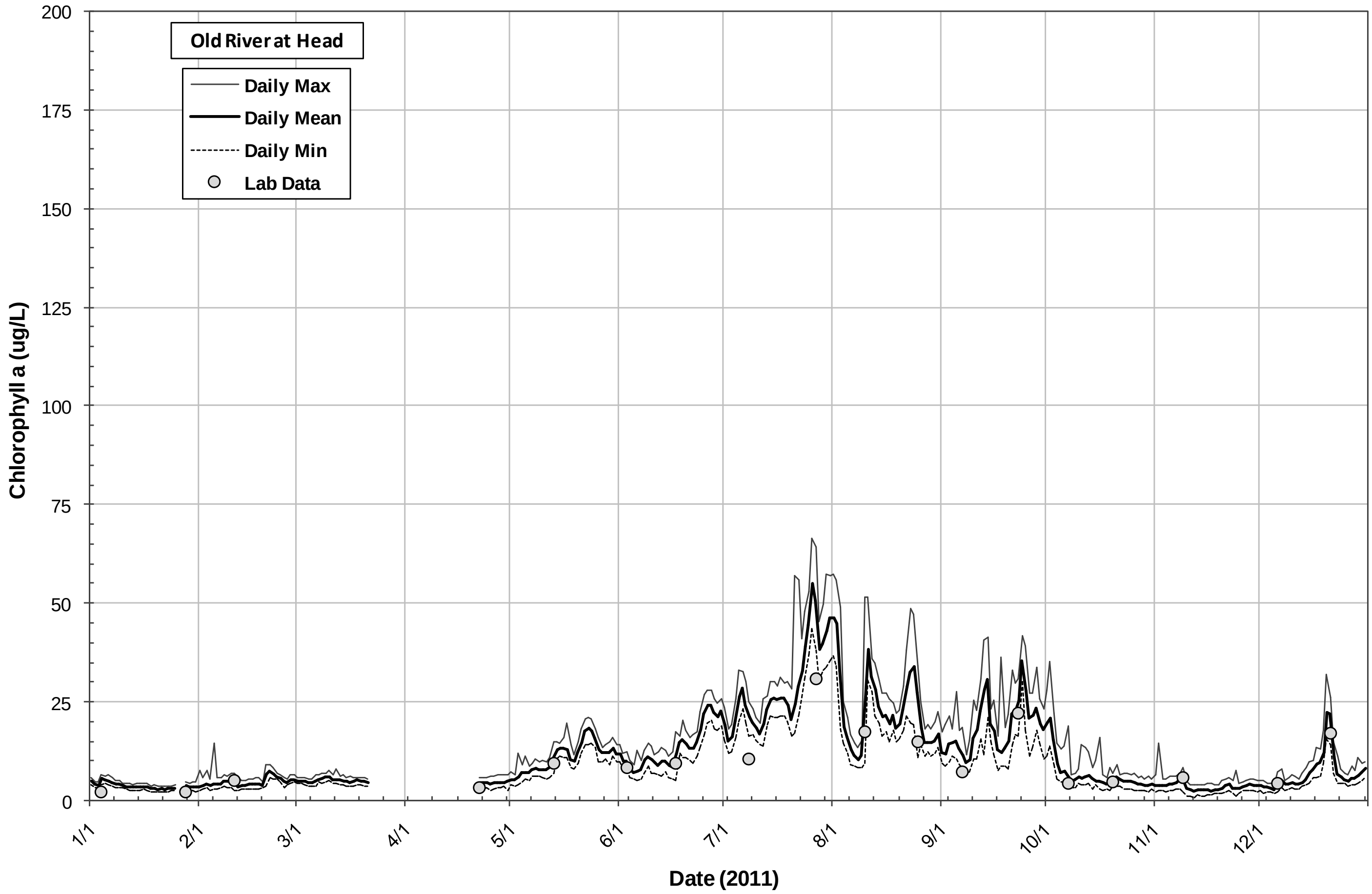


Figure 6-30: Daily Chlorophyll *a* time-series graphs for the Middle River stations



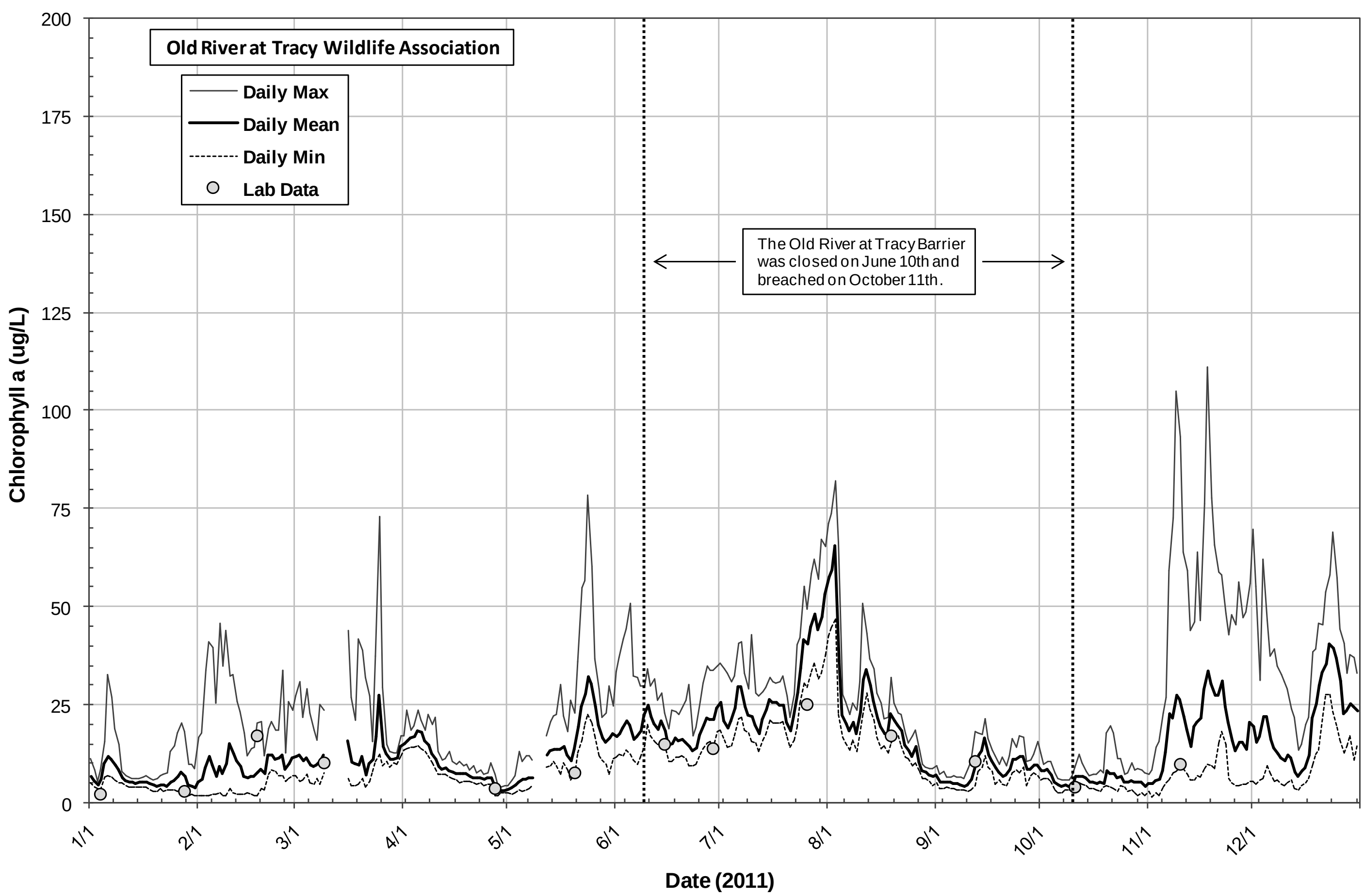
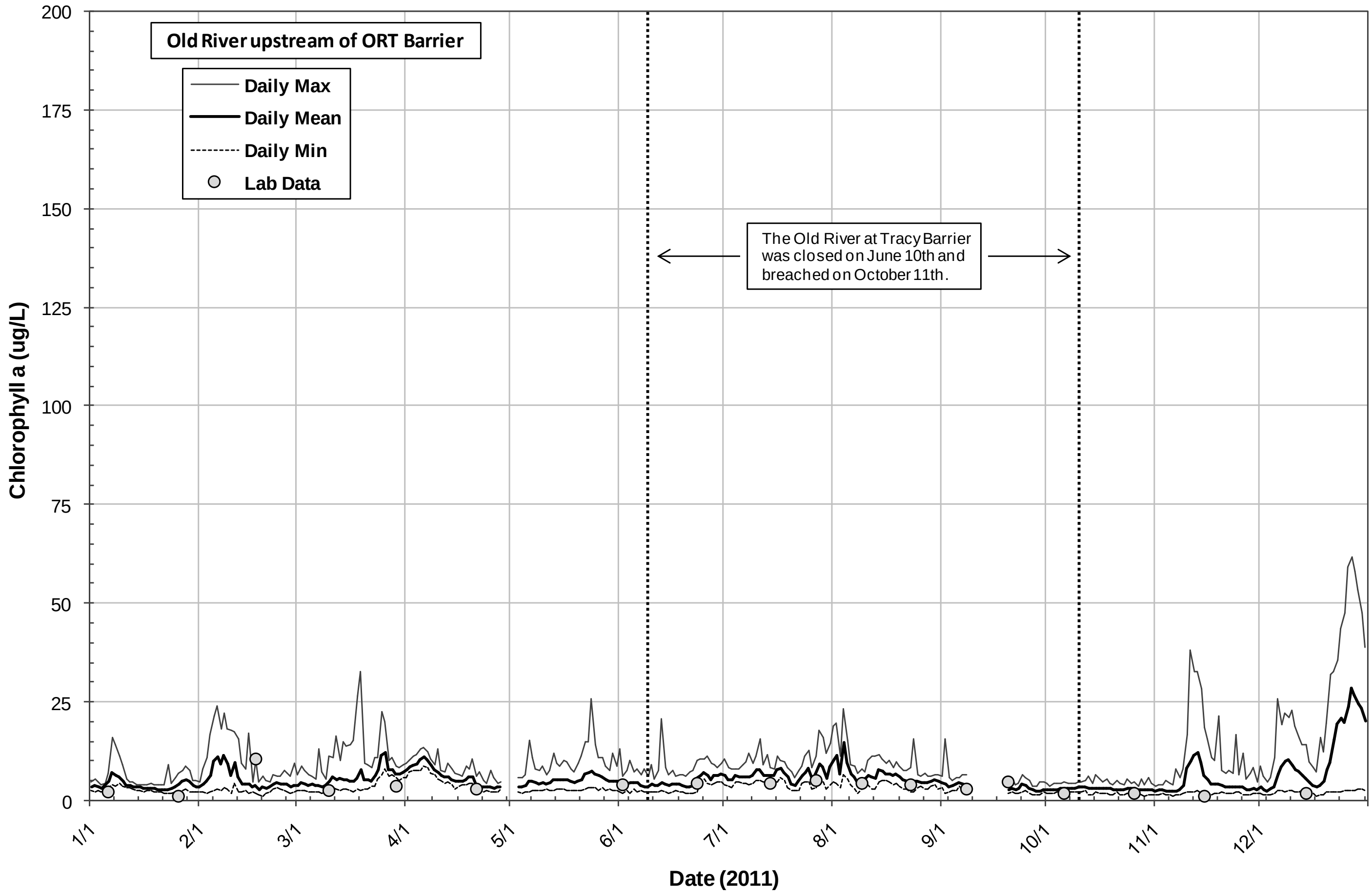


Figure 6-31: Daily Chlorophyll *a* time-series graphs for the Old River stations



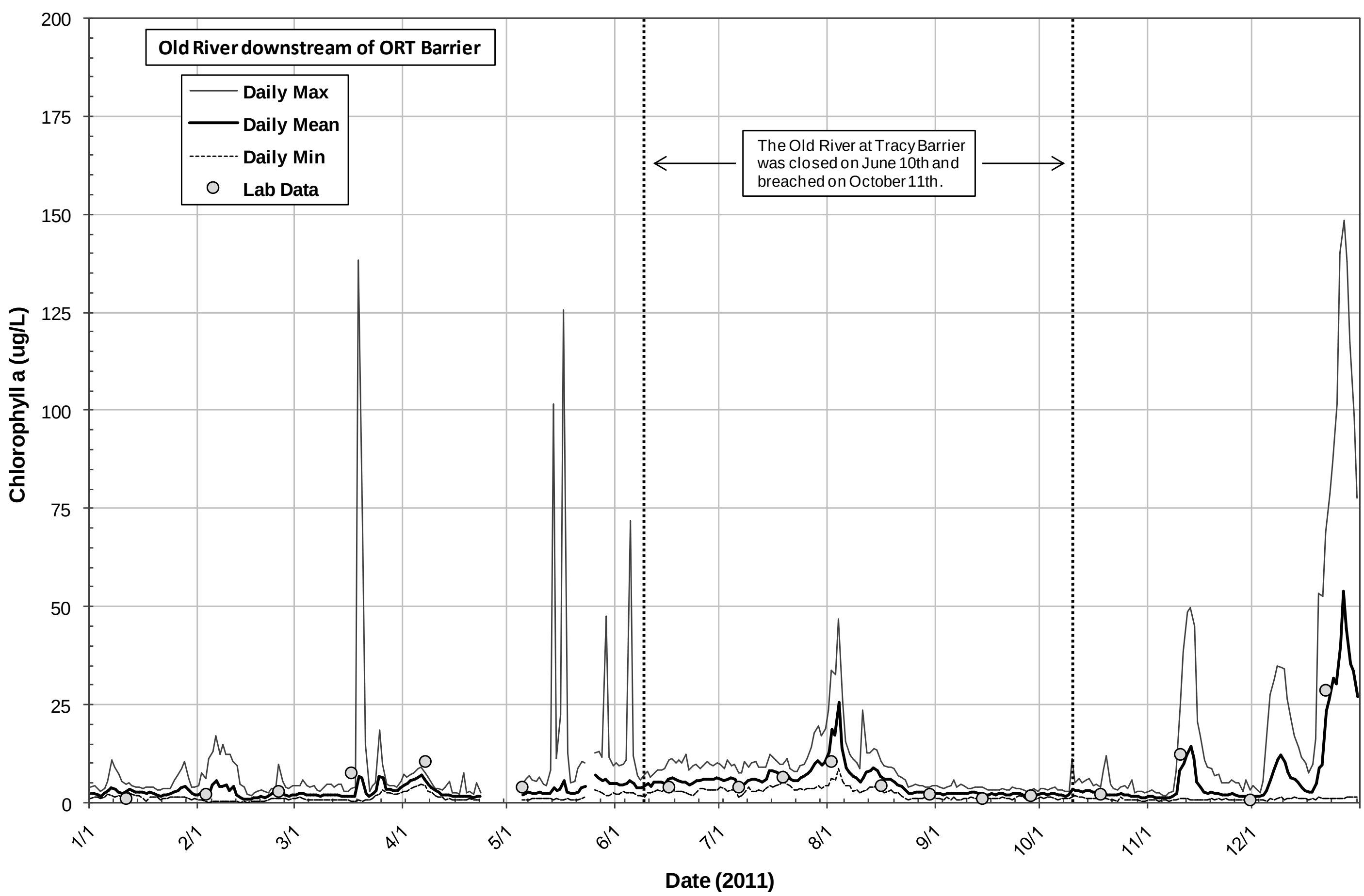


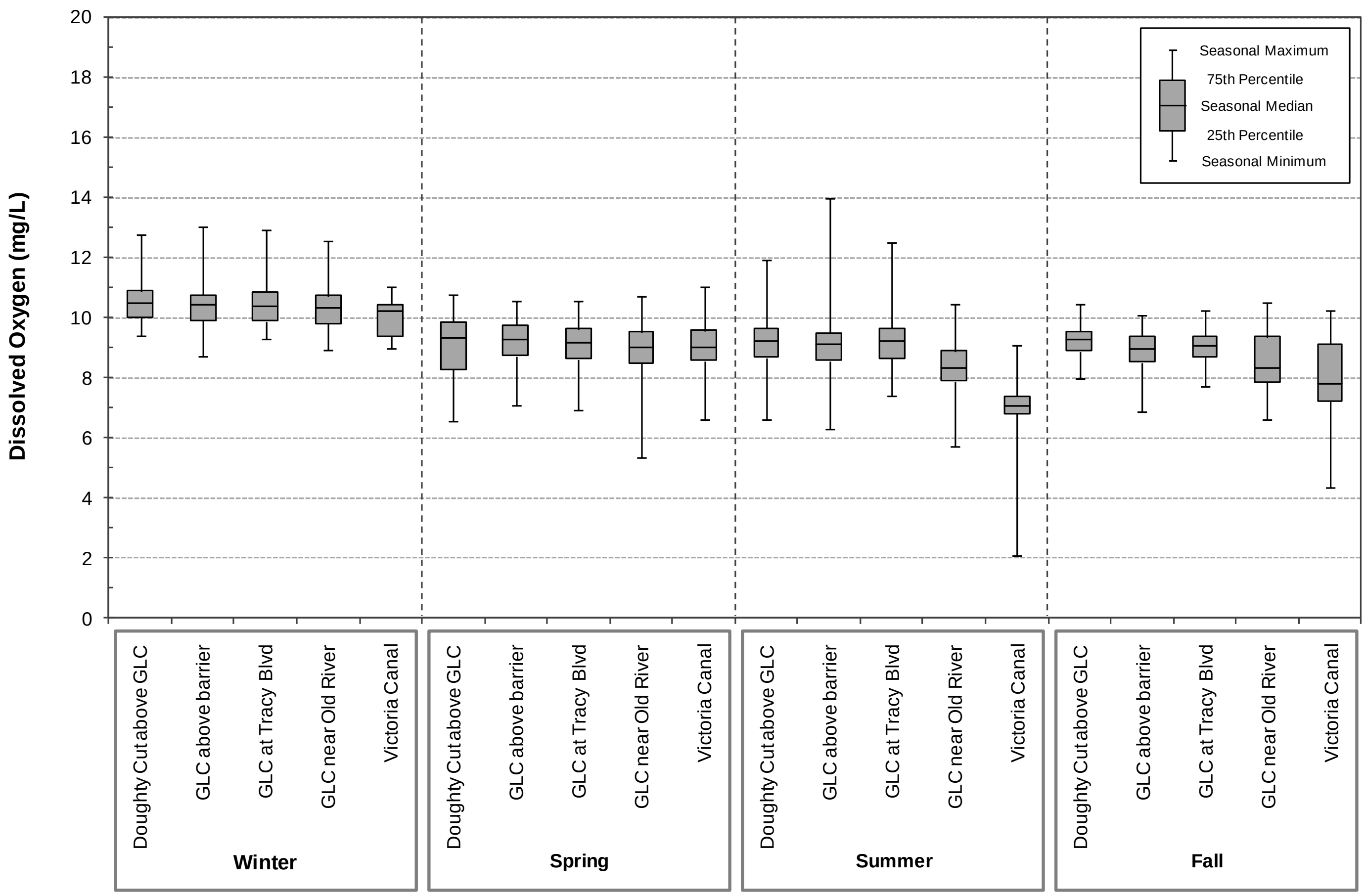
Figure 6-31: Daily Chlorophyll *a* time-series graphs for the Old River stations

DISCUSSION

Box plots illustrating the seasonal maximums and minimums, 25th and 75th percentiles, and medians for each constituent measured at the Grant Line and Victoria Canal, Middle River, and Old River stations are shown in Figures 6-32, 6-33, and 6-34, respectively. Overall trends in the 2011 water quality data collected in the South Delta are discussed below:

- A visual comparison of the 2011 water temperature plots for the South Delta monitoring sites revealed similar trends among all of the stations. This similarity is in part attributable to a common geographic location and similar meteorological conditions. Even though the sites are close to each other, variations do occur from flow, tides, barrier operation, local discharges, and bathymetry.
- Variation observed in specific conductance was due in part to differences in source water, flow dynamics, agricultural pumping, and agricultural return flows. South Delta stations with lower conductivity values throughout the year tended to be more influenced by water from the Sacramento River.
- Overall, the specific conductance, pH, and chlorophyll *a* values at all of the South Delta stations were noticeably lower throughout 2011 than they have been during recent past years. Also, most South Delta stations had more moderate dissolved oxygen concentrations with little to no supersaturation during the spring, summer, and early fall months. These differences could be partially due to the unusually wet and cool weather during the winter, spring, and early summer in 2011.
- Turbidity values at the South Delta stations were site-specific with some stations having higher or lower turbidity along the same waterbody. Stations that were more influenced by the water from the Sacramento River tended to have lower turbidity values throughout the year.

A more specific discussion of the water quality trends in 2011 for each waterbody is presented below.



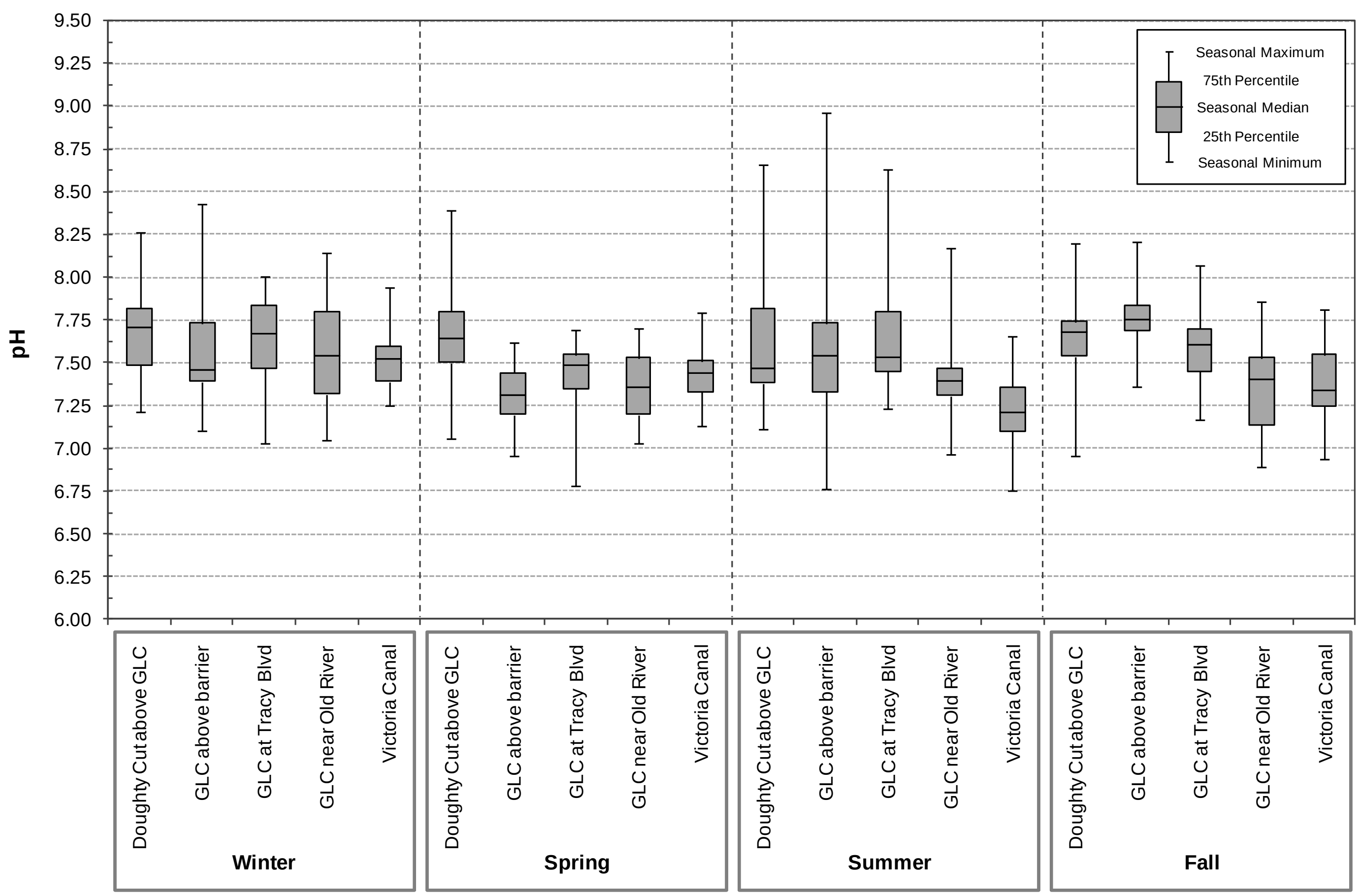
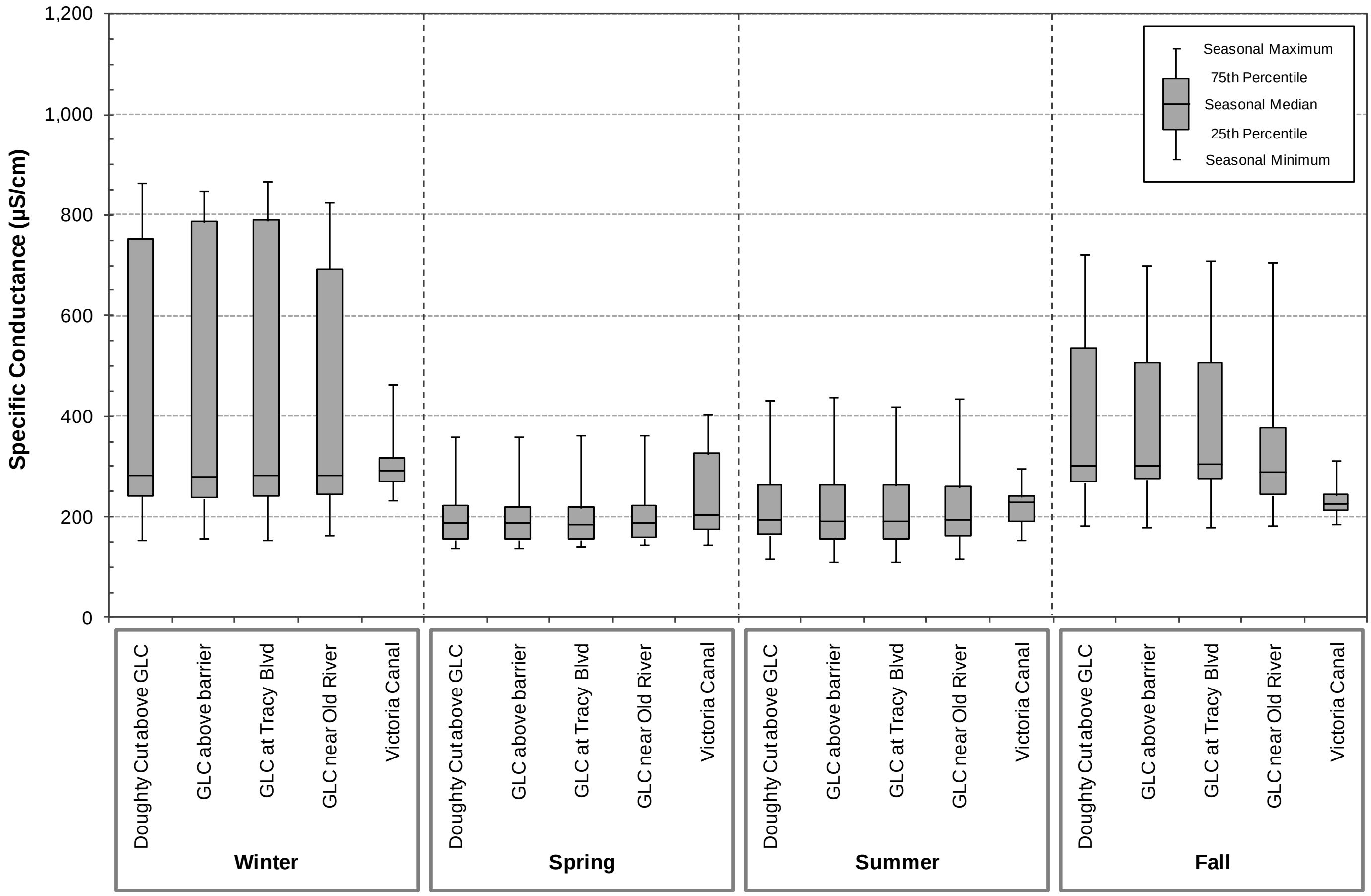


Figure 6-32: Box Plots for the Grant Line and Victoria Canal stations



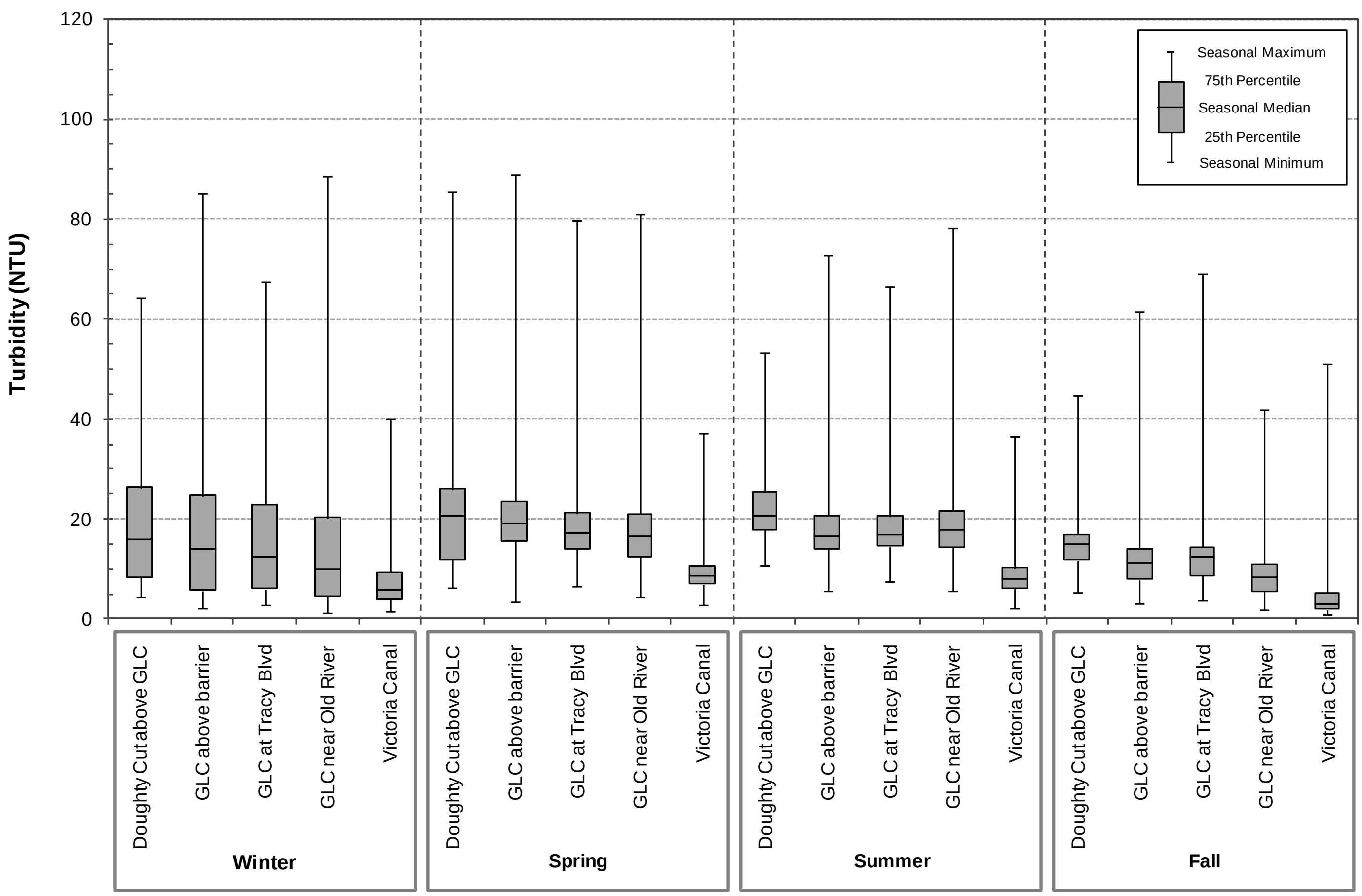


Figure 6-32: Box Plots for the Grant Line and Victoria Canal stations

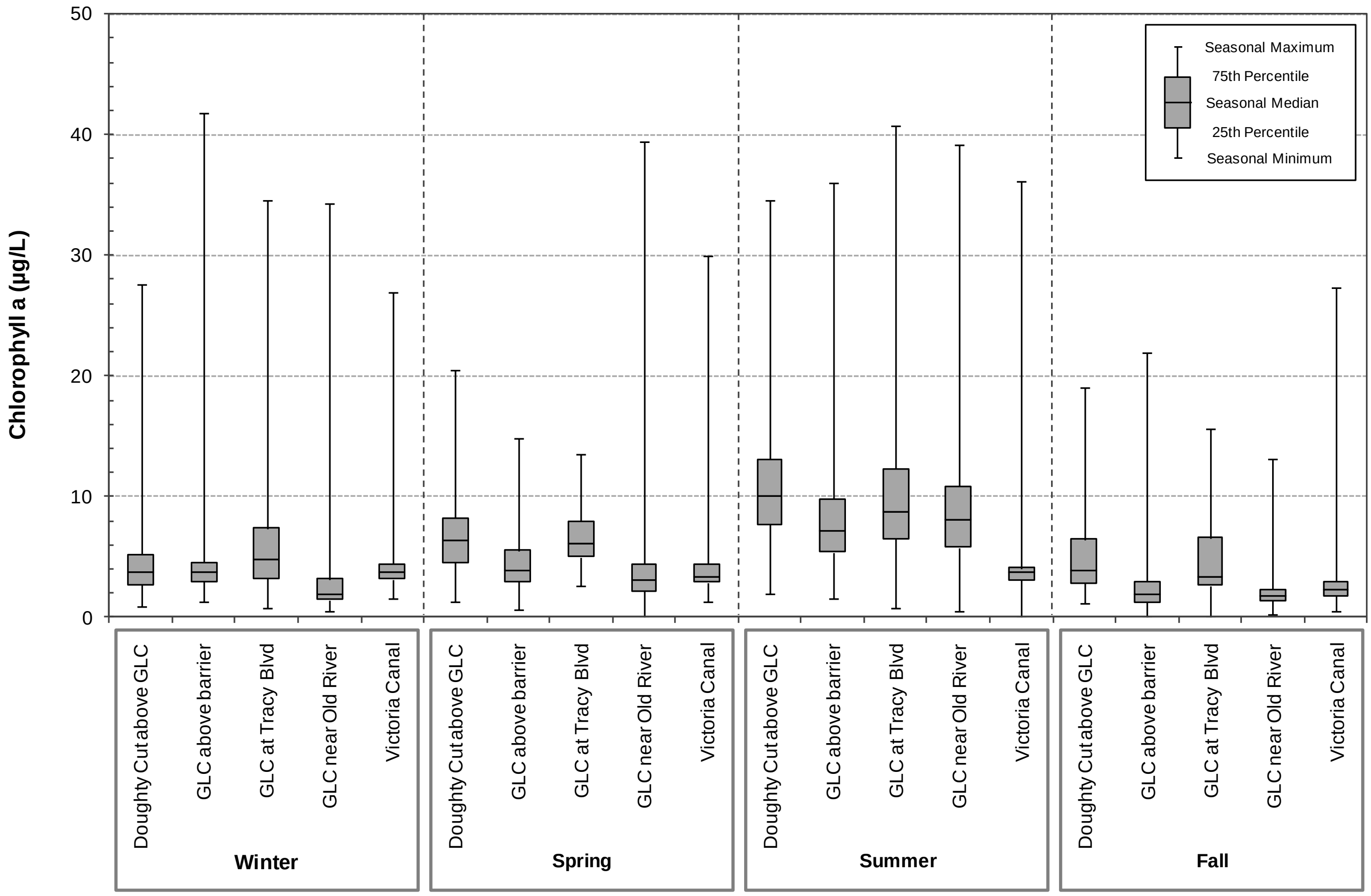
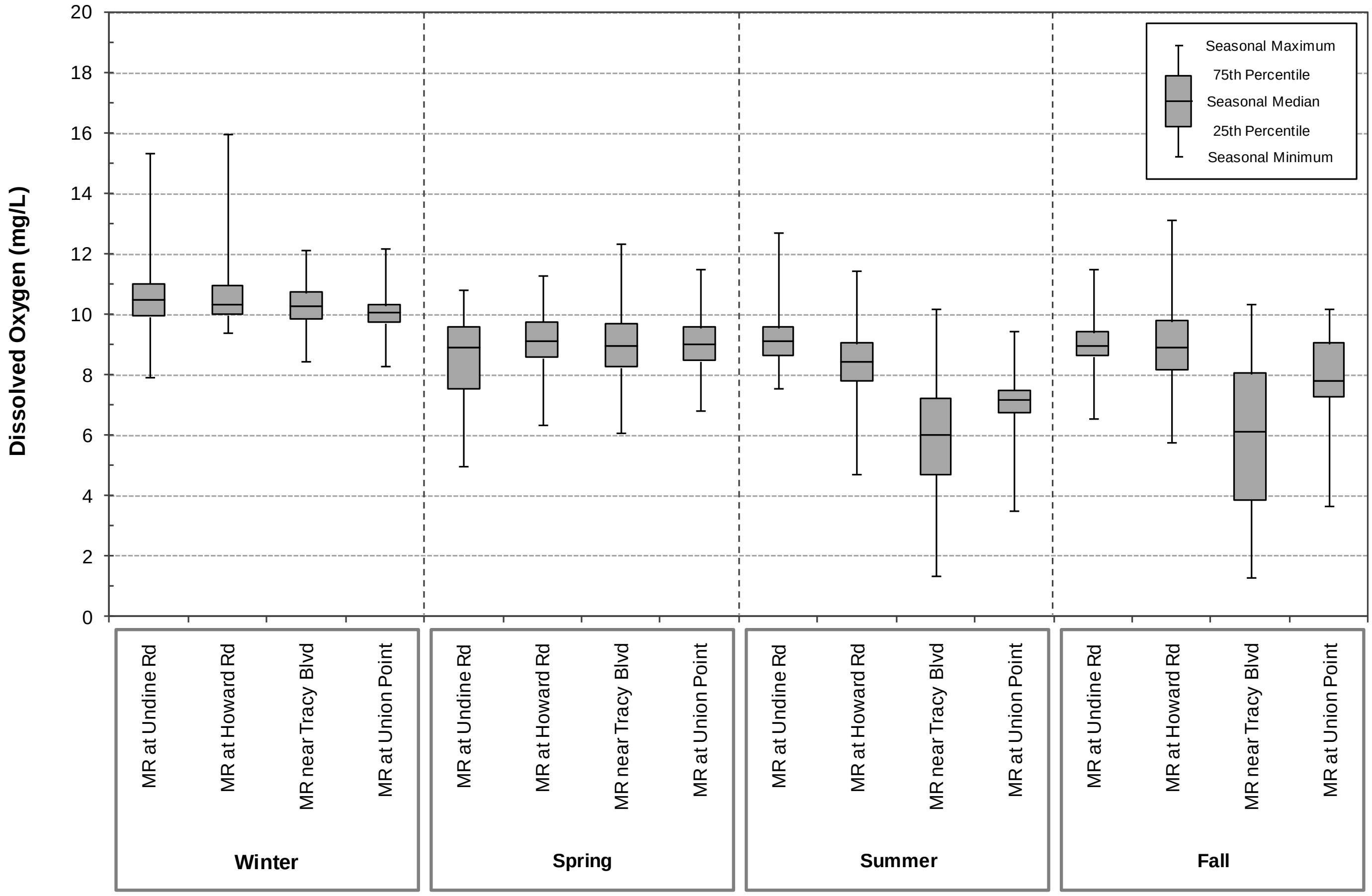


Figure 6-32: Box Plots for the Grant Line and Victoria Canal stations



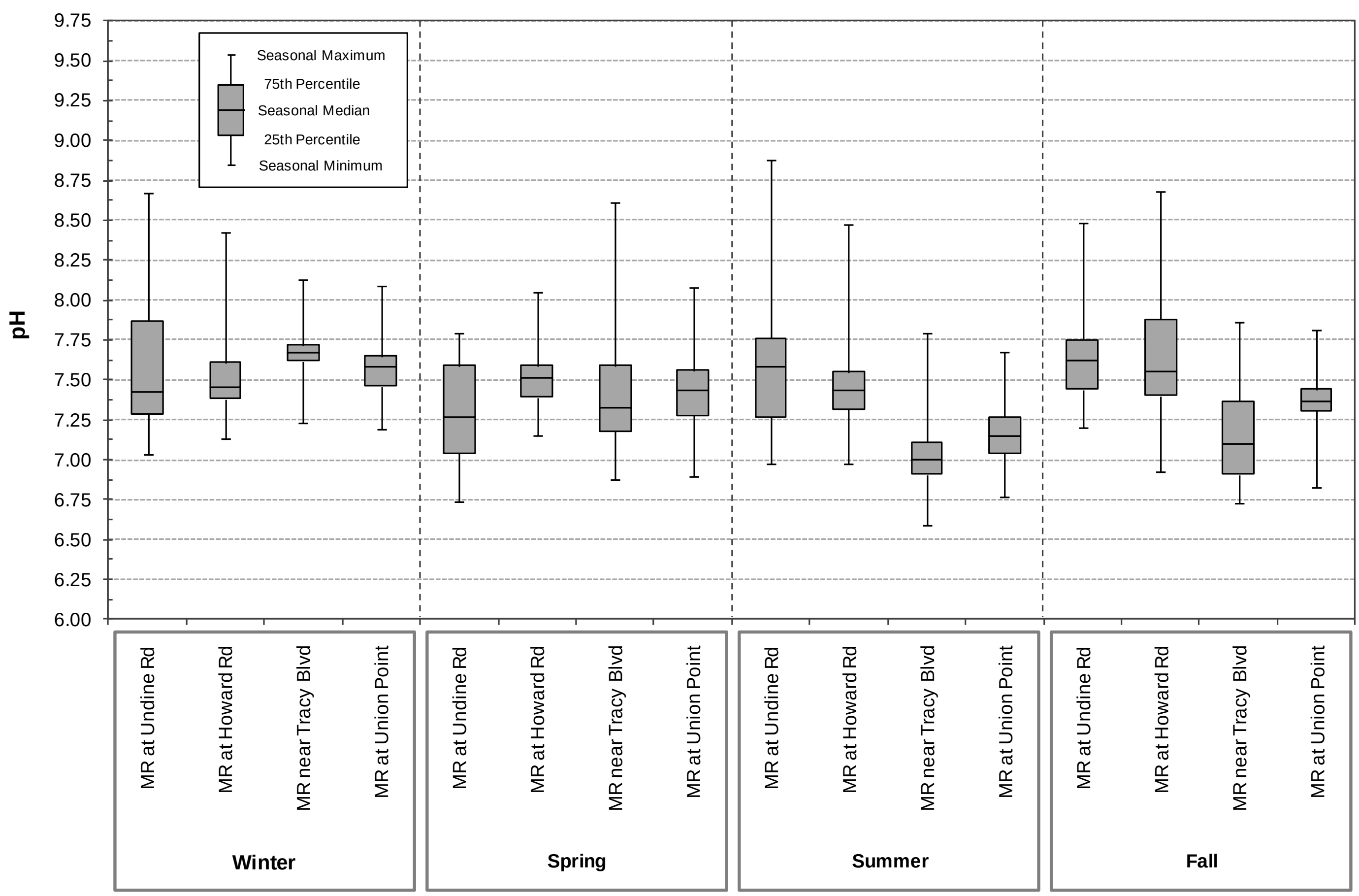
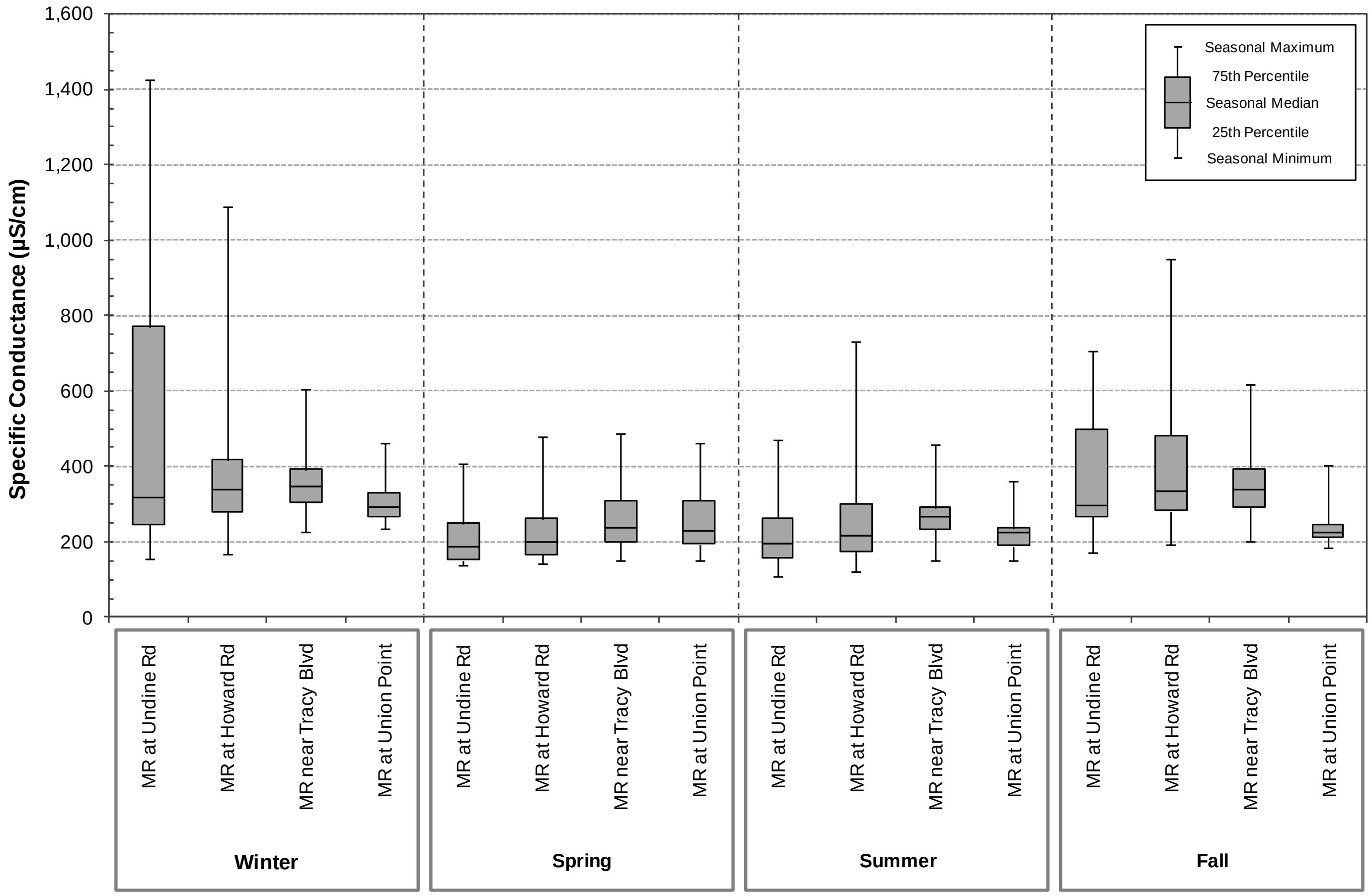


Figure 6-33: Box Plots for the Middle River stations



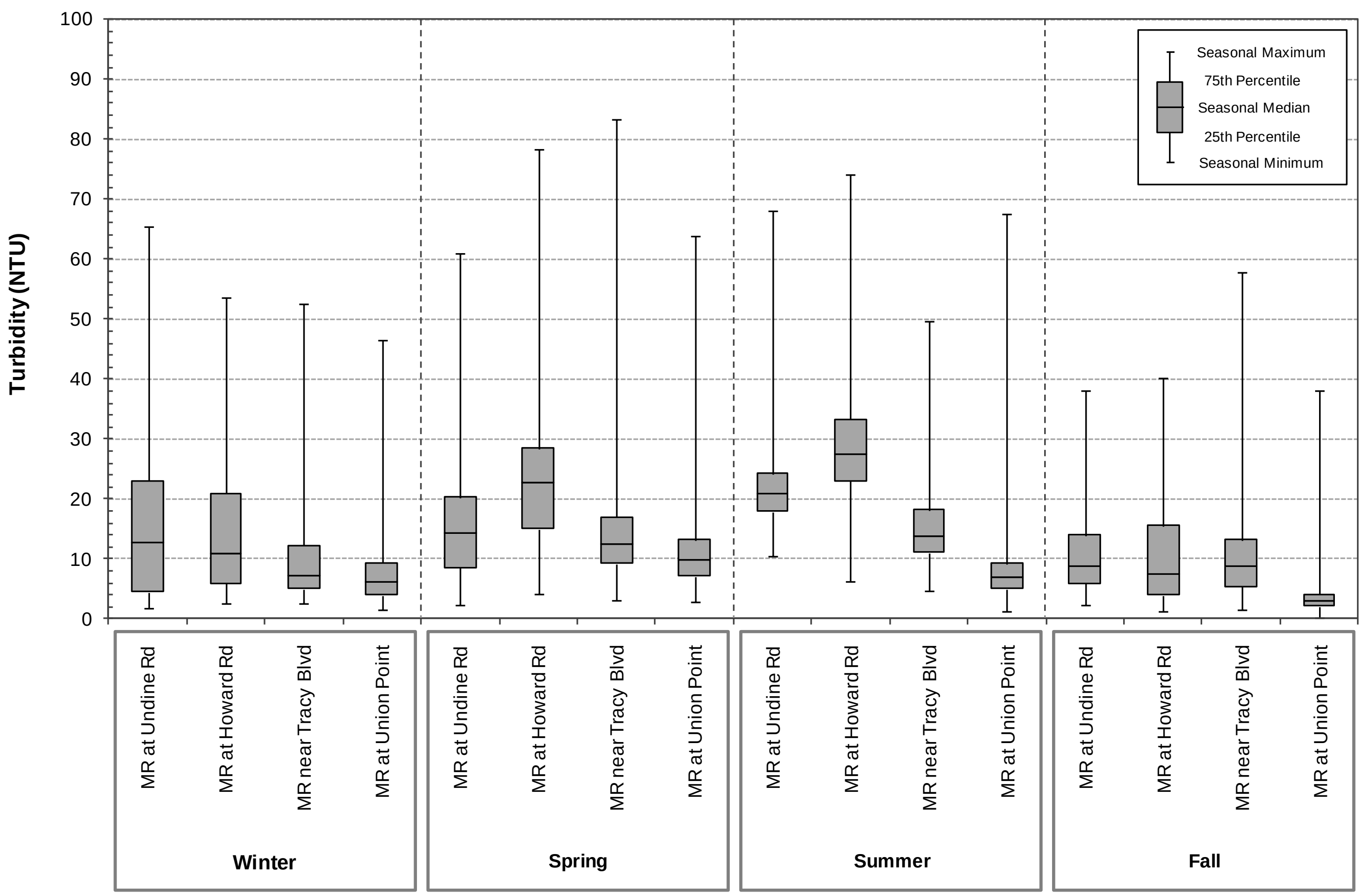


Figure 6-33: Box Plots for the Middle River stations

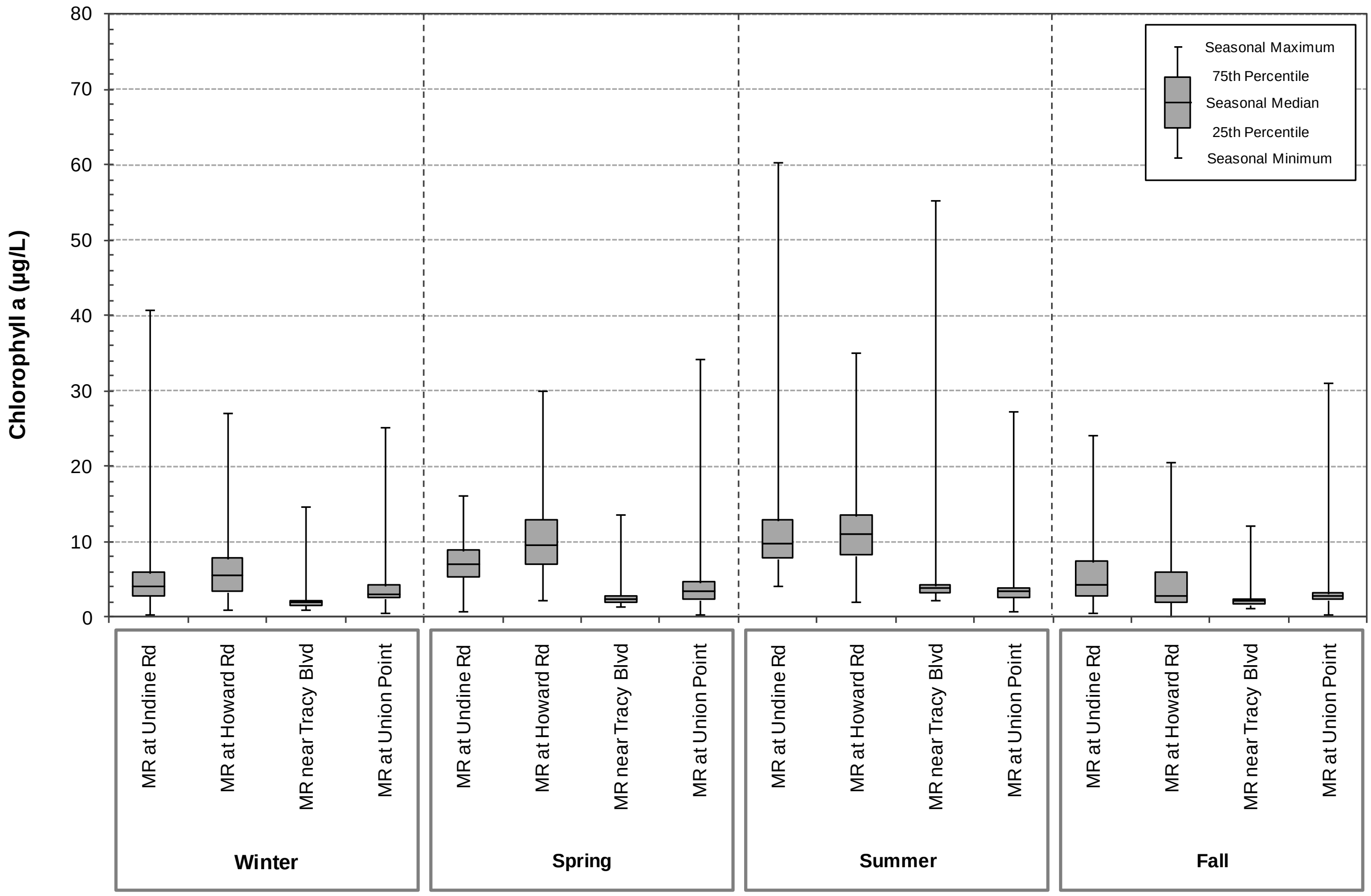
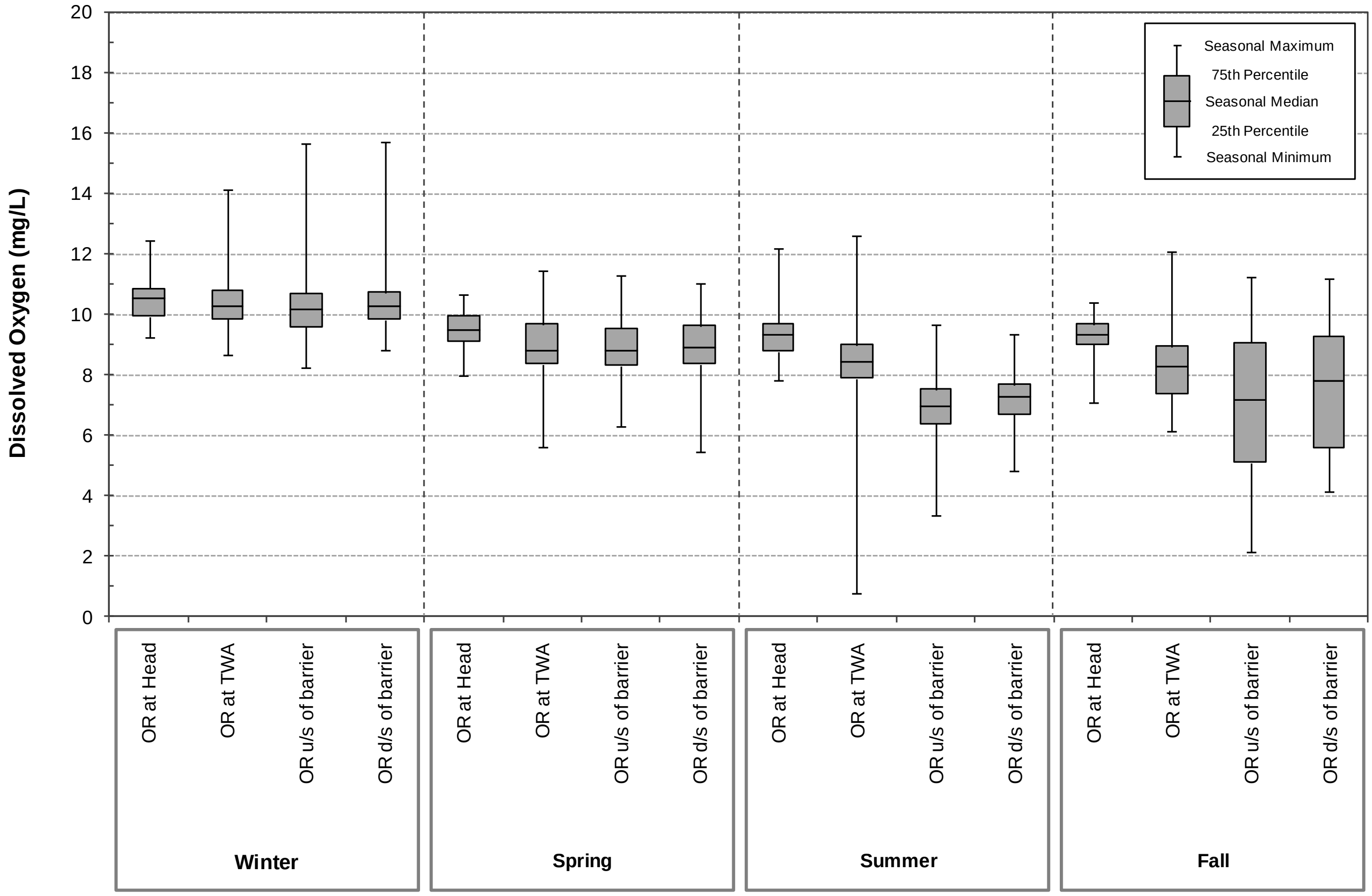


Figure 6-33: Box Plots for the Middle River stations



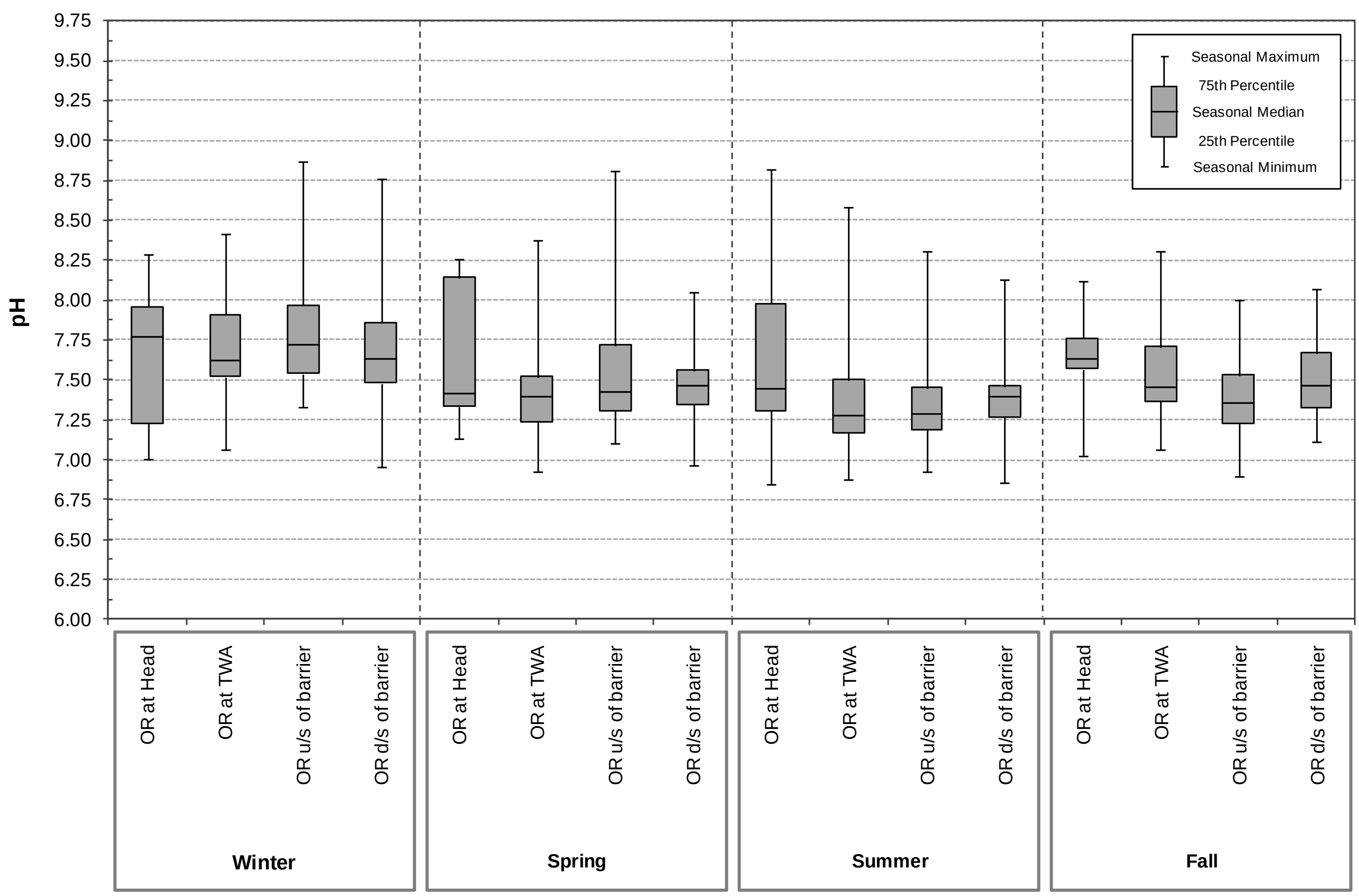
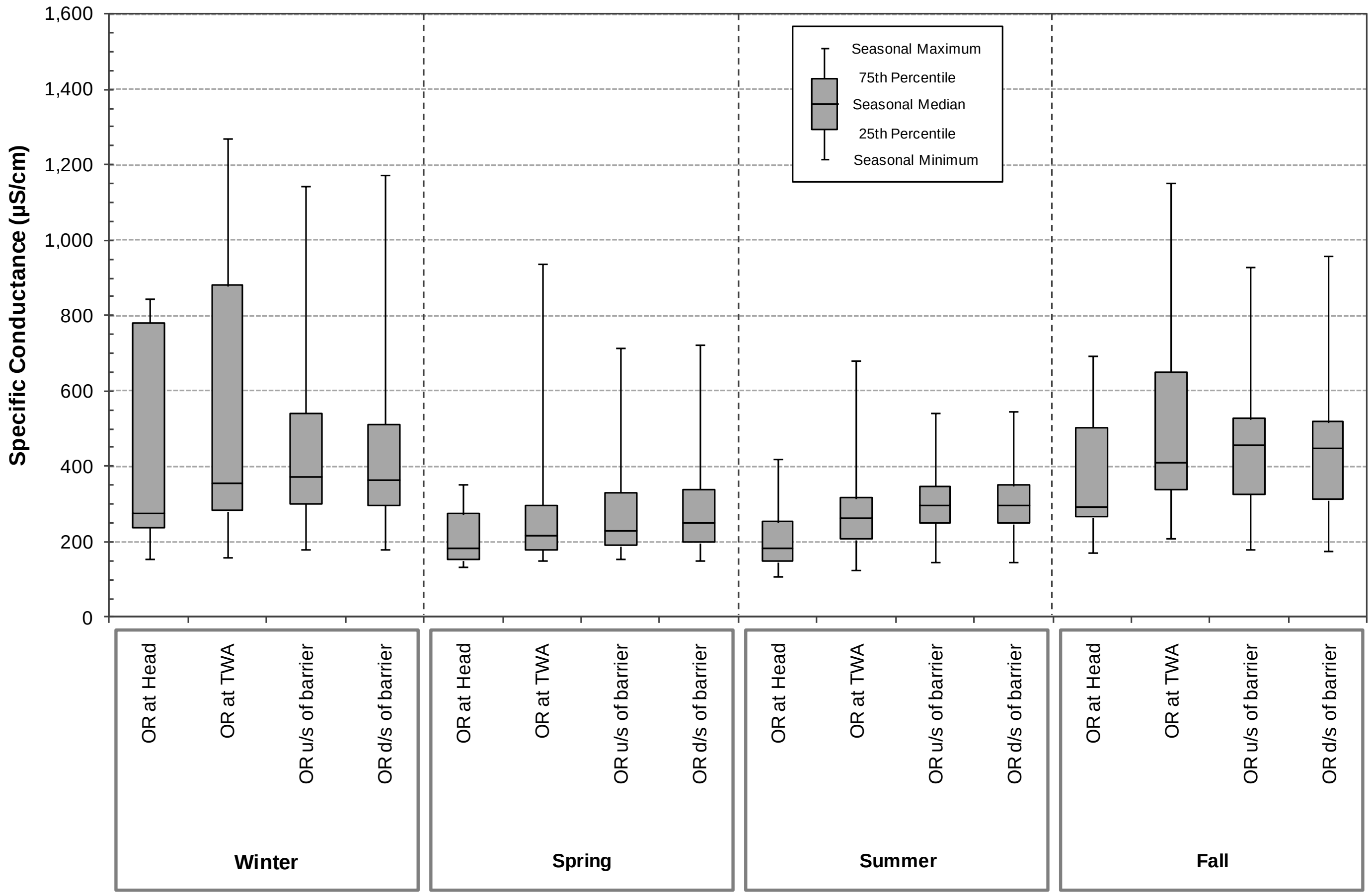


Figure 6-34: Box Plots for the Old River stations



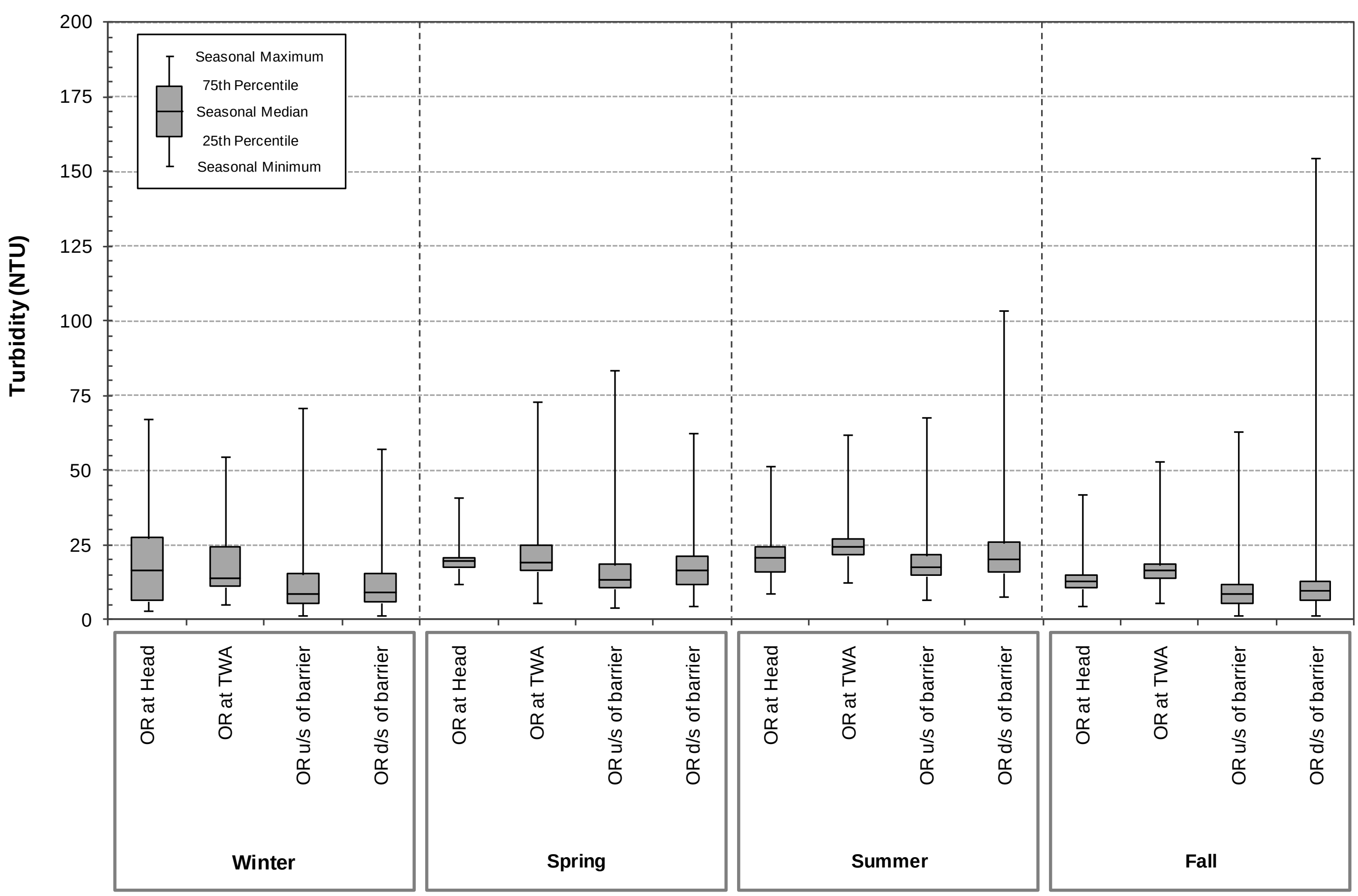


Figure 6-34: Box Plots for the Old River stations

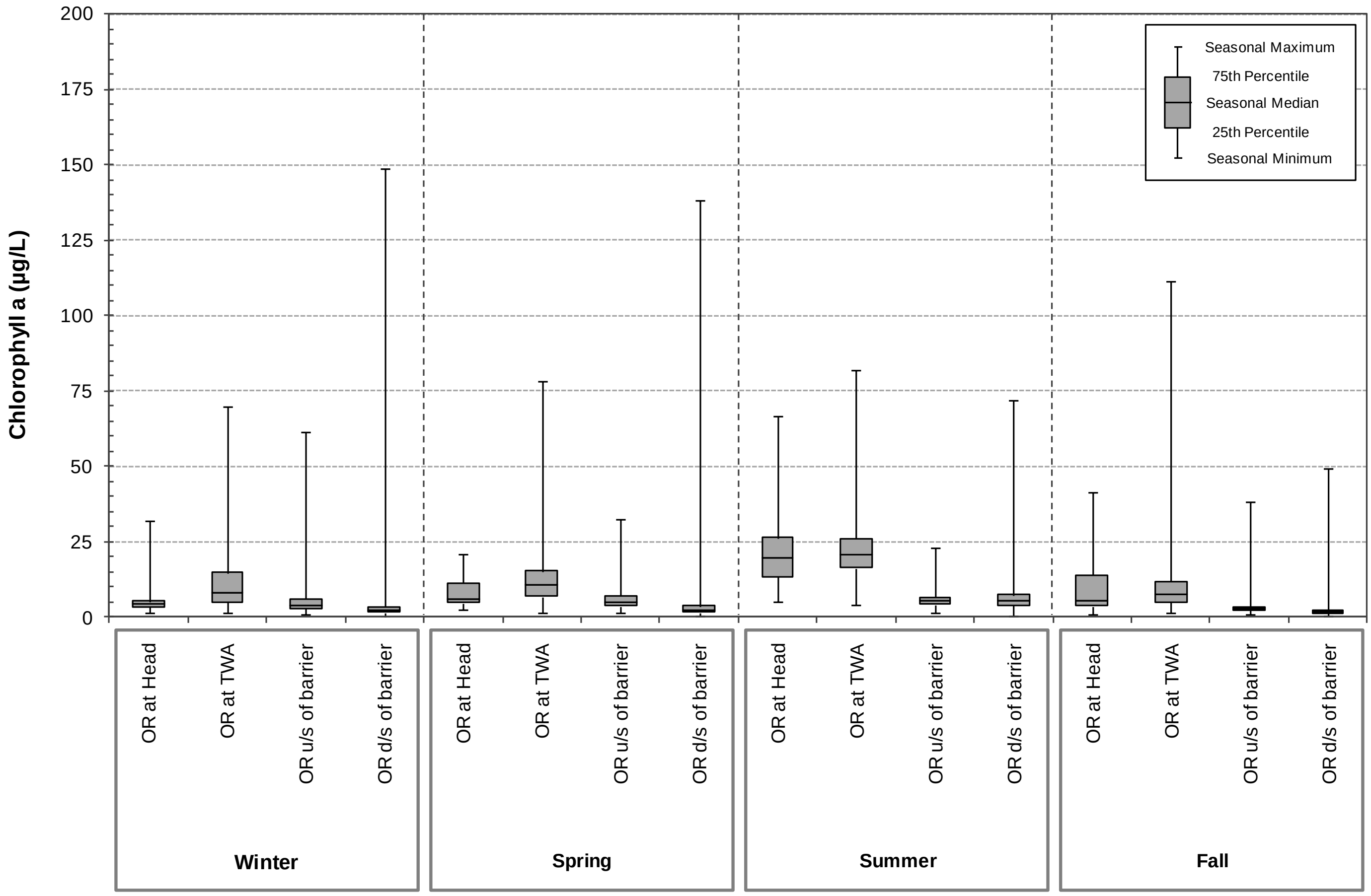


Figure 6-34: Box Plots for the Old River stations

Victoria Canal

- The water quality data measured at Victoria Canal is visibly different than the data collected at most of the continuous stations located on Grant Line Canal, Middle River, and Old River (Figure 6-32 and Table 6-4). This is most likely due to Victoria Canal receiving more water from the Sacramento River.

- The median turbidity and chlorophyll *a* values for all four seasons at Victoria Canal are visibly lower than those values observed at most of the other stations in the South Delta. Turbidity values were typically between 4 and 10 NTU throughout the year with slightly lower values in the fall (between 2 and 5 NTU). Similarly, chlorophyll *a* values were low throughout 2011, usually between 2 and 4 µg/L.

- The observed pH values at Victoria Canal were low and had little variability during the entire year, which could be related to the low chlorophyll *a* values at this site. Typically, pH values ranged between 7.1 and 7.6 during 2011 with the lowest pH values during the summer. Victoria Canal did not have a single pH sample with a value greater than 8.5 during 2011 (Figure 6-17).

- Dissolved oxygen concentrations were also fairly consistent during the first half of the year at Victoria Canal with typical values between 8.5 and 10.5 mg/L with slightly higher values in the winter and early spring. Concentrations noticeably dropped during the summer and early fall with typical values usually between 6.8 and 7.4 mg/L (Figures 6-5 and 6-32). Victoria Canal had 4 total dissolved oxygen samples with a value less than 5.0 mg/L during 2011 (Figure 6-8). Dissolved oxygen concentrations increased up to about 10 to 10.5 mg/L again towards the end of 2011.

Grant Line Canal

- The Doughty Cut above Grant Line Canal, Grant Line Canal above the GLC barrier, Grant Line Canal at Tracy Blvd, and Grant Line Canal near Old River stations all had almost identical specific conductance values during the winter, spring, and summer of 2011 (Figure 6-32). It appears that during most of the year the higher flows in the South Delta due to the extremely wet winter and spring caused the water to be fairly uniform nearby all four of the Grant Line Canal stations.

- Specific conductance levels dramatically increased at all four Grant Line Canal stations starting at the beginning of November, and then became more steady at about 800 µS/cm at the beginning of December through the end of the year (Figure 6-23). Of these four stations, Grant Line Canal near Old River had lower specific conductance values with much more variability in November and December 2011. Average specific conductance values at this station were about 100 µS/cm lower than the other three stations during December. As flows decreased in the fall due to the drier than normal conditions, there may have been more water from Old River mixing with the water nearby the Grant Line Canal near Old River station causing its specific conductance values to be lower and more variable.

- All four of the Grant Line Canal stations had very low chlorophyll *a* concentrations during the entire year with only slightly elevated concentrations in the summer (Figures 6-29 and 6-32, Table 6-3). This indicates that very little algal photosynthesis was occurring in the water nearby these stations throughout 2011. Typical values during the winter, spring, and fall seasons ranged from 2 to 8 µg/L, and values during the summer ranged from 6 to 13 µg/L. Maximum adjusted chlorophyll *a* concentrations reached about 40 µg/L during the summer at the four Grant Line Canal stations. There was also a slight increase in chlorophyll *a* concentrations at all four stations at the end of 2011.

- The four Grant Line Canal stations had much lower and less variable pH values in 2011 when compared to recent years (Figures 6-14 and 6-32, Table 6-3). During the winter, spring, and early summer, pH values typically ranged between 7.2 and 7.8 at all four stations. pH values at Doughty Cut above Grant Line Canal, Grant Line Canal above the GLC barrier, and Grant Line Canal at Tracy Blvd increased slightly at the end of the summer and early fall, which corresponds with the period of slightly increased chlorophyll *a* concentrations. There was no increase in pH values at the Grant Line Canal near Old River station during the late summer and early fall.

- The Grant Line Canal stations all had very low numbers of pH standard exceedences during 2011 with the highest number being 108 at Grant Line Canal above the GLC barrier (Figure 6-17). Grant Line Canal near Old River did not have a single pH sample with a value greater than 8.5 during the year.

- Dissolved oxygen concentrations at the four Grant Line Canal stations were fairly consistent throughout the year and ranged between 9.8 to 10.5 mg/L in the winter, 8.4 to 9.8 mg/L in the spring, 7.9 to 9.6 mg/L in the summer, and 8.5 to 9.4 mg/L in the fall (Figure 6-32). All four of these stations did not have a single dissolved oxygen sample with a value less than 5.0 mg/L during the year (Figure 6-8).

- The Doughty Cut above Grant Line Canal, Grant Line Canal above the GLC barrier, and Grant Line Canal at Tracy Blvd stations all had two distinct periods of time with slightly elevated and possibly supersaturated dissolved oxygen concentrations: one in August and the other in December (Figure 6-5). These times correspond with the two periods of slightly increased chlorophyll *a* concentrations at these stations. In contrast, dissolved oxygen concentrations did not increase during August at Grant Line Canal near Old River.

- Grant Line Canal near Old River had significantly lower dissolved oxygen concentrations during the summer and fall months than the three other stations along Grant Line Canal ($p<0.0006$; Tables 6-8 and 6-9). However, the differences between Grant Line Canal near Old River and the three other stations were fairly small with median values being 0.7 to 1.1 mg/L lower. Seasonal median dissolved oxygen concentrations at the Grant Line Canal near Old River station were 8.21 mg/L in the summer and 8.23 mg/L in the fall.

- Doughty Cut above Grant Line Canal had consistently higher turbidity values by approximately 2-7 NTU than the three other stations located along Grant Line Canal (Figure 6-32). This same trend has been observed in past years as well. Although the differences in turbidity values were small, the consistently higher turbidity values at the Doughty Cut station throughout 2011 is noteworthy, and may be due to its site characteristics. The Doughty Cut station is situated in a shallow location with a bottom composed of silt that can be agitated into the water column by wave action.

Middle River

- All four Middle River stations had very similar specific conductance values during the winter, spring, and summer of 2011 (Figure 6-33 and Table 6-5). The Middle River at Union Point station had visibly lower specific conductance values than the three other Middle River stations during the fall. Specific conductance levels increased at the end of 2011 at all of the Middle River stations, most significantly at Middle River at Undine Road and Middle River at Howard Road (Figure 6-24). Values at these two stations increased dramatically up to 800-900 µS/cm.

- Middle River at Howard Road had brief periods of highly elevated specific conductance values throughout much of the year (Figure 6-24). These significant spikes in specific conductance values have occurred in prior years at this station, and are likely the result of flow dynamics, agricultural pumping, and agricultural return flows. Middle River at Undine Road also had specific conductance spikes during January and February.

- Both the Middle River near Tracy Blvd and Middle River at Union Point stations had very low chlorophyll *a* concentrations throughout the year with values typically between 2 to 5 µg/L (Figure 6-33 and Table 6-5). The Undine Road and Howard Road stations generally had higher chlorophyll *a* concentrations, but with typical values between 2 to 14 µg/L these two stations had much lower values than during recent years. Middle River at Undine Road and Middle River at Howard Road had slightly elevated chlorophyll *a* concentrations during the late summer, early fall, and the month of December (Figure 6-30).

- The four Middle River stations also had much lower and less variable pH values in 2011 when compared to recent years (Figures 6-15 and 6-33, Table 6-5). pH values at the Undine Road and Howard Road stations increased slightly at the end of the summer and early fall, which corresponds with the period of slightly increased chlorophyll *a* concentrations. Middle River near Tracy Blvd and Middle River at Union Point had consistently low pH values throughout the entire year.

- All of the Middle River stations had very low numbers of pH standard exceedences during 2011 with the highest number being 369 at Middle River at Undine Road (Figure 6-18). Middle River near Tracy Blvd and Middle River at Union Point had one and zero pH exceedences in 2011, respectively.

- Almost all of the pair-wise comparisons of median dissolved oxygen concentrations between the Middle River stations were significantly different during the summer and fall ($p<0.004$; Tables 6-11 and 6-12). The most notable difference was Middle River near Tracy Blvd compared to the three other stations. This station had much lower and more variable dissolved oxygen concentrations during the summer and fall with typical values between 3.9 and 8.0 mg/L (Figure 6-33). In addition, the near Tracy Blvd station had a period of 62 consecutive days from the beginning of August to the beginning of October where the daily average dissolved oxygen concentrations were below 5 mg/L (Figure 6-6). Middle River at Union Point also had slightly lower dissolved oxygen concentrations during the summer and fall. It appears that the low dissolved oxygen problem that usually affects the Howard Road station shifted further downstream in 2011 towards the Middle River near Tracy Blvd station.

- Middle River near Tracy Blvd also had the highest number of dissolved oxygen standard exceedences out of all of the South Delta stations. In 2011, the near Tracy Blvd station had 5,680 dissolved oxygen samples with values less than 5.0 mg/L (Figure 6-9). All of these standard exceedences occurred in the summer and fall with 2,627 and 3,053, respectively. The three other Middle River stations had low numbers of dissolved oxygen standard exceedences during the year (between 1 and 57).

- Middle River at Howard Road had visibly higher turbidity values than the three other Middle River stations during the spring and summer with typical values ranging between 15 to 33 NTU (Figure 6-33). In addition, Middle River at Undine Road had higher turbidity levels than Middle River near Tracy Blvd and Middle River at Union Point during the summer. The Union Point station had the lowest turbidity values throughout the year with values typically between 2 and 13 NTU.

Old River

- All four Old River stations had fairly similar specific conductance values during the spring and summer of 2011 (Figure 6-34 and Table 6-6). Specific conductance levels dramatically increased to about 800 µS/cm in December at all of the Middle River stations (Figure 6-25). The two stations adjacent to the ORT barrier, Old River upstream of the barrier and Old River downstream of the barrier, had a lot of daily variability in their specific conductance values during November and December, which was during the same time period as when specific conductance was increasing.

- Old River at Tracy Wildlife Association had highly variable specific conductance values during the winter and early spring (Figure 6-25). Values ranged from a minimum of 161 µS/cm and a maximum of 939 µS/cm during this time period (Table 6-6). Old River at Tracy Wildlife Association also had slightly higher specific conductance levels than the three other Old River stations in the fall to the end of the year (Figure 6-25).

- Old River at Head and Old River at Tracy Wildlife Association had higher chlorophyll *a* concentrations throughout the year than the two stations adjacent to the ORT barrier (Figure 6-34 and Table 6-6). The Head and Tracy Wildlife stations had elevated chlorophyll *a* concentrations during the summer and fall (Figure 6-31). However, with typical concentrations between 4 and 26 µg/L during this time period, these two Old River stations had lower values in 2011 than during recent years.

- The two stations adjacent to the ORT barrier, Old River upstream of the barrier and Old River downstream of the barrier, had low chlorophyll *a* concentrations during the winter, spring, and summer with values typically between 2 to 8 µg/L (Figure 6-34). The Old River downstream of the ORT barrier station had a slight increase in chlorophyll *a* concentrations in August, but not at the same magnitude as at the Head and Tracy Wildlife stations (Figure 6-31).

- All four Old River stations had an obvious increase in chlorophyll *a* concentrations in November and/or December 2011 (Figure 6-31). This interesting trend occurred at almost every South Delta station this year.

- pH values were much lower and less variable in 2011 at the four Old River stations when compared to recent years (Figures 6-16 and 6-34, Table 6-6). Old River at Head appeared to have higher pH values than the three other Old River stations throughout the year. pH values at all four stations increased slightly in August and in November through December, which corresponds with the two periods of elevated chlorophyll *a* concentrations that occurred at most of these stations (Figure 6-16).

- All of the Old River stations had low numbers of pH standard exceedences during 2011 with the highest number being 744 at Old River upstream of the ORT barrier (Figure 6-19). Interestingly, about half of the exceedences at this station occurred during the month of March when chlorophyll *a* concentrations were low across the South Delta. The station with the second highest number of pH standard exceedences was Old River downstream of the barrier with 242. Old River at Head and Old River at Tracy Wildlife had 213 and 19 exceedences, respectively.

- The two stations closest to the ORT barrier had lower dissolved oxygen concentrations than the two upstream stations, Old River at Tracy Wildlife Association and Old River at Head, during the summer and fall (Figure 6-34 and Table 6-6). These differences were statistically significant during the summer ($p<0.00001$; Table 6-14). In addition, the upstream of the ORT barrier station had significantly lower concentrations than the Head and Tracy Wildlife stations in the fall ($p<0.006$;

Table 6-15). Of the two stations adjacent to the ORT barrier, the upstream station appeared to have slightly lower dissolved oxygen concentrations during the summer and fall.

- All four of the Old River stations had slightly elevated dissolved oxygen concentrations during the month of August, which corresponds with the period of time with slightly increased chlorophyll *a* concentrations in this area (Figure 6-7). The Old River at Head station had significantly higher dissolved oxygen concentrations than the three other Old River stations during the spring, summer, and fall ($p<0.0003$; Tables 6-13 to 6-15).

- The two Old River stations closest to the ORT barrier had higher numbers of dissolved oxygen standard exceedences than the two upstream sites (Figure 6-10). In 2011, Old River upstream of the barrier had a total of 2,128 dissolved oxygen samples with values less than 5.0 mg/L, and the downstream of the barrier station had 753 exceedences. In contrast, the Old River at Head and Old River at Tracy Wildlife stations had zero and three dissolved oxygen standard exceedences, respectively.

- All of the Old River stations had fairly similar turbidity values throughout the year with typical values ranging between 6 and 27 NTU (Figure 6-34). Old River at Tracy Wildlife had slightly higher values than the three other stations during the spring, summer, and fall with values typically 3 to 7 NTU higher.

CONCLUSIONS AND RECOMMENDATIONS

Continuous data collection at the 13 South Delta monitoring locations in 2011 revealed the following overall trends:

- Specific conductance values were low throughout the South Delta during the winter, spring and summer of 2011. All of the 13 stations had some increase in specific conductance values during the end of the year. The Middle River at Howard Road and Middle River at Undine Road stations also had brief periods of highly elevated specific conductance values. Victoria Canal and Middle River at Union Point had some of the lowest conductance values throughout 2011.
- Doughty Cut, Middle River at Undine Road, Middle River at Howard Road, and Old River at Tracy Wildlife Association all had higher turbidity values throughout 2011. Victoria Canal and Middle River at Union Point had some of the lowest turbidity values during the year.
- All of the South Delta stations had relatively low chlorophyll *a* values during 2011 when compared to recent years. The stations with the highest chlorophyll *a* values in the summer and early fall were Old River at Tracy Wildlife Association and Old River at Head. All of the South Delta stations except for Victoria Canal, Middle River at Union Point, and Middle River near Tracy Blvd had elevated chlorophyll *a* values at the end of 2011.
- All of the South Delta stations also had relatively low pH values during 2011 when compared to recent years.
- Middle River near Tracy Blvd, Old River upstream of the ORT barrier, and Old River downstream of the barrier all had some of the lowest dissolved oxygen concentrations in the summer and early fall. Of these three stations, Middle River near Tracy Blvd had the lowest concentrations.

DWR staff have the following recommendations for future water quality studies in the South Delta:

- Additional studies and analyses are necessary to determine the relationships between dissolved oxygen concentrations and factors such as algal biomass, biological oxygen demand, and flow at the area between Middle River at Howard Road and Middle River near Tracy Blvd. Similar studies and analyses could be done at the stations nearby the ORT and GLC barriers.

- Data from the monitoring stations on Sugar and Paradise Cuts should be analyzed to help understand the influences of these water bodies on specific conductance values at Old River at Tracy Wildlife Association.
- Studies should be done to determine the sources of the brief periods of highly elevated specific conductance values at Middle River at Howard Road and Undine Road.
- DWR staff will be conducting long-term trend analyses to reveal any changes in water quality parameters at the 13 South Delta stations.

Monitoring will continue in 2012 at all 13 stations to supplement: (1) the existing time-series record, (2) provide historical data, and (3) to meet the requirements outlined in the 401 Water Quality Certification for the Temporary Barriers Project.

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